

A Framework for Assessing Interventions  
to Promote the Implementation of Material Innovations  
on Construction Projects

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Declaration

I, Kell Jones, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed

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Dated

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## **Abstract**

Recent research has highlighted that the UK construction industry must accelerate the implementation of novel material solutions (NMS) with low embodied greenhouse gases (GHG) onto projects to decouple growth in construction activity from embodied GHG emissions. To reduce the risks in this process of transition, there is a need to examine the unsystematic promotion of interventions to encourage NMS implementation.

Autoethnography was used with constructivist grounded theory in an abductive exploration of construction NMS (non-)implementation, synthesising qualitative data from interviews, surveys, participatory and non-participatory observations with the existing literature. Adopting the specification decision as the appropriate unit of analysis, the research applied a novel morphogenetic perspective of structure and agency to develop a new framework in which the NMS specification decision could be located and assessed. The framework contributes to both theory and practice by allowing a systematic exploration of the specification decision and its elaborating impacts enabling the selection of case-appropriate interventions to influence project actors' capability, opportunity and motivations to implement NMS on projects. The research provides insights for policy makers, practitioners and researchers wishing to promote NMS.

The model highlights the critical influence of the timing of sanctionable project decisions, the availability of sufficient project resources, and the client's project performance objectives on successful NMS implementation on projects.

Keywords:

*Construction; Autoethnography; Decision-making; Behaviour Change; Construction innovation.*

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## Impact Statement

If the UK is to meet its 2050 obligations under the Paris Treaty and Climate Change Act, the UK construction industry will need to adopt new ways of building using novel material solutions (NMS). In a slow-changing industry this creates a significant transition risk of dislocation for industry actors and the wider economy. This Engineering Doctorate proposes actionable interventions to smooth the transition to the routine use of NMS, supporting the delivery of the UK's commitments to help avoid the impacts of a changing global climate. The proposals presented are directed towards actors in the UK construction industry, but can be adapted to other contexts.

### *Policy, Institutions, Economy and Industry*

This thesis argues that transition risks can be reduced by encouraging NMS implementation on projects in the short to medium term by either:

- making NMS implementation the source of competitive advantage, through the use of supportive policy and regulation, or
- socialising the risks across the industry, making the transition a pre-competitive challenge.

Delivering this impact requires the engagement and coordination of many industry actors, creating an awareness of the transition risks to encourage early experimentation with and implementation of NMS. Dissemination of the findings of this thesis can help to promote coordinated action. The dissemination process has already begun through blog postings, presentations, trade publications and conferences. If funding were available, a communication and engagement strategy could be planned, and subsequently implemented with industry support.

### *Industrial Partners*

This thesis has advanced the knowledge of innovation implementation at the project's industrial partner through internal knowledge sharing and researcher input to projects. However, the theoretical insights developed here supporting project-by-project NMS implementation must be operationalised. Developing the necessary methodology to review a project's context could be the subject of a master's dissertation.

### *Academia*

The production of a new operational, morphogenetic middle-range model of the construction project provides construction management researchers with the opportunity to locate their work in a broader, coordinated context. This will enable more effective and systematic identification of practical research gaps, enhancing the practical impact of future research, avoiding duplication or unnecessary research. To ensure academic impact from this thesis, it is important that key insights be published by the author.

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## Papers Arising from this Research

The research supporting this thesis has led to the following publications, conference presentations and papers.

### Peer reviewed articles

Jones, K., Stegemann, J.A, Sykes, J. and Winslow, P. (2016). 'Adoption of Unconventional Approaches in Construction: The Case of Cross-laminated Timber'. *Construction and Building Materials* 125. This paper is reproduced in Appendix F.

### Cited in Peer Reviewed Journals:

Guerrero, J. E. and Hansen, E. (2018) 'Cross-sector Collaboration in the Forest Products Industry: A Review of the Literature', *Canadian Journal of Forest Research*. doi:10.1139/cjfr-2018-0032.

Roelich, K. and Gieseckam, J. (2018) 'Decision Making Under Uncertainty in Climate Change Mitigation: Introducing Multiple Actor Motivations, Agency and Influence', *Climate Policy* doi: 10.1080/14693062.2018.1479238.

Kuzman, M. K. et al. (2018) 'Architect Perceptions of Engineered Wood Products: An Exploratory Study of Selected Countries in Central and Southeast Europe', *Construction and Building Materials*, 179, pp. 360–370.

Gieseckam, J., Tingley, D. D. and Cotton, I. (2018) 'Aligning carbon targets for construction with (inter)national climate change mitigation commitments', *Energy and Buildings*. 165(January)

Rose, C. and Stegemann, J.A. (2018) 'From Waste Management to Component Management in the Construction Industry'. *Sustainability*, 10(1)

Nguyen, H.D., Nguyen, L.D., Chih, Y.Y., Le-Hoai, L., (2017) 'Influence of Participants' Characteristics on Sustainable Building Practices in Emerging Economies: Empirical Case Study'. *Journal of Construction Engineering and Management* 143 (8)

Guo, H. and Liu, Y. (2017). 'A Comparison of the Energy Saving and Carbon Reduction Performance between Reinforced Concrete and Cross-Laminated Timber Structures in Residential Buildings in the Severe Cold Region of China'. *Sustainability* 9(8), p. 1426.

Mercader-Moyano, P., García-de-la-Cruz, M.V.R, Yajnes, M.E. (2017) 'Development of New Eco-Efficient Cement-Based Construction Materials and Recycled Fine Aggregates and EPS from CDW', *The Open Construction & Building Technology Journal*, 2017(11)

## Conference papers

Chapter 8 is based, in part, on a paper presented at the *Bartlett 2017 Doctoral Conference on Sustainable Built Environment*: 'Effecting Change in Construction: The Construction Project as Decision Set', UCL. A copy of this paper is included as Appendix G.

Chapter 9 is based, in part, on a paper presented at the *International Association for Bridge & Structural Engineering (IABSE) 2017 Conference. Creativity & Collaboration*. 'Construction Innovation: Theory & Practice', Bath University. A copy of this paper is included as Appendix H.

*SBE16 International Conference on Sustainable Built Environment PhD session*: 'Overcoming Barriers to the Adoption of Unconventional Materials in Construction', Hamburg. This paper explored is explored further in Appendix C

*WASCON 2014 Resource Efficiency in Construction* 'Exploring the Underlying Barriers to the Adoption of Novel Materials in the UK Construction Industry', Santander. This paper presents early findings from Jones et al., (2016)

## Industry articles

Jones, K., Martin, B. & Winslow, P. 2017. 'Innovation in Structural Engineering - The Art of the Possible'. *The Structural Engineer* 95(1). This article is included in Appendix I.

*“... it is not the most intellectual of the species that survives; it is not the strongest that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself.”*

*Megginson, 1963*

*“There is a fundamental fear of getting it wrong.”*

*Data point AT*

*“Well, ... it sort of depends...”*

*Interview 1*

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## Acknowledgments

My doctoral programme has been a time for reflection. This has led to a rich exploration of the fascinating construction industry in which I have worked for the past few years. The results of that reflection are presented in this thesis. Equally rich, however, has been the exploration of my own self. My development in both of these fields has been transformative. My thanks go to those who provoked these reflections.

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## List of Abbreviations and Acronyms

BREEAM	The Building Research Establishment Environmental Assessment Methodology
CLT	Cross-Laminated Timber
COM-B	Capability, Opportunity, Motivation – Behaviour
DMS	Dominant Material Solutions
DMU	Decision-making Unit
EPD	Environmental Product Declaration
GBT	Green Building Technologies
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
MLP	Multi-Level Perspective (on Technology Transitions)
NMS	Novel Material Solutions
PBO	Project-Based Organisation
PESTLE	Political, Economic, Social, Technological, Legal, Environmental
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
SEM	Structural Equation Modelling
TCE	Transaction Cost Economics
TRL	Technology Readiness Level
UKGBC	UK Green Building Council
UKGCB	UK Green Construction Board

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## Preface

In 2005 I left my role as a consultant to help address the growing crisis of climate change through the design of 'sustainable' buildings. Working as an architectural technologist, designer and material specifier on projects it soon became clear that while I could make initial material proposals, I had little influence over what actually ended up on a project. Someone else, somewhere in the project team, typically with different priorities from mine would make the final decision. I had almost given up hope of delivering meaningful change when I saw an opportunity: sister companies Expedition Engineering and Useful Projects were, like me, frustrated at the conservatism of the construction industry and were funding research to understand how to make change happen on construction projects. I was excited to help them.

I was welcomed into the organisation and soon became part of the family, sitting and working alongside some of the most creative and highly regarded sustainability experts, structural and civil engineers in the world. I spent time talking to my new colleagues and others, listening to their project discussions to understand how they had innovated, or failed to, on projects. In my project work, I tried to translate the construction innovation literature I was reading to practice, to influence the specification choices of designers and the project team. But I found that the solutions proposed in the literature were far removed from the messiness and specificity of practice, typically generic, often inappropriate, and usually ineffective. Finding nothing in the literature addressing the constraint rich, multi-party and dynamic circumstances I found myself in, I was unable to create the behaviour change I felt was necessary. Informed by these failed project interventions, discussions, interviews, and my own extensive and iterative reflections, I developed a new way of thinking about construction projects that brings order and specificity to the messiness of construction.

My desire to understand and describe how to create change on a construction project has guided this study, leading me down some unusual paths for construction research. My prior experience and training as economist, accountant, consultant and material specifier have illuminated that path, influencing what I consider important to addressing this challenge. As such, this thesis represents a form of analytical autoethnography, describing my subjective process of sense-making of the problem of construction innovation. However, aware that this thesis was to be delivered as an engineering doctorate, to an audience consisting primarily of engineers, I have largely absented myself from the words that follow. But, to be clear, I am behind every word.

Especially the part about sloths.

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# 1 Introduction

## 1.1 Summary of the Research Problem

Responding to the challenges of man-made climate change (IPCC, 2014) requires the rapid diffusion of new ways of creating the built environment (WBCSD, 2010; Allwood et al., 2012), including the use of new materials and construction processes. However, a conservative construction industry appears reluctant to implement the novel, resource efficient technologies necessary to address these challenges (Williams and Dair, 2007; Jones et al., 2016). Those in the industry seeking to promote the use of novel technologies have had limited success (Steele, Hurst and Gieseckam, 2015) in the face of cost and risk lock-in to dominant practices and a fragmented and highly competitive industry (Ofori, 1991; Egan, 1998; Sheffer and Levitt, 2010; Jones et al., 2016). Adopting the position of an actor seeking to advance novel technologies on construction projects, this thesis describes the findings of a practice-based exploration of the problem of implementing novel technologies on a project-by-project basis.

This chapter introduces the research project and the practical context in which it is located.

## 1.2 The Global Challenge to Reduce Greenhouse Gas (GHG) Emissions

The global population is forecast to grow by a third from 7.3bn to approximately 9.7bn by 2050 and 11.2bn by 2100 (UNDESAP, 2017). Each individual in this population has a legitimate aspiration of a 'good life'. If current consumption patterns continue, this population growth will increase the demand on the planet's limited resources. Among these resources are a group of 'common resources' that are not currently controlled in a market context, which require particular attention (Hardin, 1968). One such common resource is the earth's capacity to accumulate greenhouse gases (GHG) without changing climate such that it becomes inhospitable to human life.

The accumulation of anthropogenic GHG emissions in the Earth's atmosphere is believed to be causing a warming of the global systems (IPCC, 2013). This warming is expected to affect the climate of the planet, termed 'man-made climate change'. Projections suggest that temperature increases will raise the likelihood of future extreme local weather events such as drought, flooding and storms, affecting the poorest in society most (IPCC, 2014). While the impacts on society today are relatively limited, current inaction is considered to be creating problems for future generations, creating a moral imperative to act. The UN's Conference of Parties at Paris in 2015 produced a near global consensus (the 'Paris Agreement') on the need to limit the emission of GHG to hold the increase in global temperatures to well below 2°C above pre-industrial levels (UNFCCC, 2015). The parties also agreed to aim to move to a 'net-zero carbon' economy in the second half of this century "... *to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases...*" (UNFCCC, 2015). This will require significant reductions in the emission of GHG across the globe. The planet is currently tracking above the highest of the UN's modelling scenarios (Sanford et al.,

2014). This suggests that the planet is heading towards a temperature increase between 2.6°C to 4.8°C by 2100, with a mean projection of 3.7°C (IPCC, 2013). Insurers have warned that assets may become uninsurable at these levels of temperature increase due to chaotic impacts on weather (Medland, 2015).

Until recently, the emission of GHG was not considered to be problematic, and as such, emissions have not previously been regulated or subjected to property rights. Hardin (1968; after Lloyd 1832) describes how the use of a common resource in the individual pursuit of rational self-interest, without some form of control, can lead to the collapse of the stock of that resource. This phenomenon is described as 'The Tragedy of the Commons'. It is now evident that if the planet is to avoid the problems of a warming climate, there are limits to the GHG that can be emitted into the atmosphere. The GHG emissions of any one individual or organisation in pursuit of their own objectives might be considered inconsequential. Collectively, however, projected emissions are beyond the carrying capacity of the planet to keep temperatures within acceptable bounds. The emission of GHG represents a classic 'commons' problem.

On a global scale, buildings account for around one third of GHG emissions (IRP, 2017). Reducing the intensity of GHG emissions in construction is therefore important for increasing industrial and economic resilience (COM(2014) 398 Final, 2014). Despite the imperative to reduce GHG emissions, there remains a need to deliver the infrastructure, homes and workplaces for an increasing population. This ongoing demand presents three key challenges for the construction sector:

- a need to reduce the GHG emissions related to the production and operation of newly constructed built assets (HMG, 2013b);
- a need to reduce the resource intensity of the production of the built environment (COM(2011) 571 Final, 2011); and
- a need to construct buildings and infrastructure that are resilient to future climate change (Prasad et al., 2009).

This thesis addresses the first of these challenges by promoting materials and processes that reduce the GHG emitted in the production of the built environment. Collectively, these lower impact materials, technologies and processes are described as Novel Material Solutions (NMS). Novelty here relates to the first use of a material or process by a unit (after Rothwell, 1992).

### **1.3 The Greenhouse Gas Challenge for the UK Construction Industry**

The UK Government introduced the Climate Change Act (2008) ('The Act') to formalise the UK's commitment to achieving the necessary global reductions in GHG. The Act requires that UK GHG emissions fall by 80% from 1990 levels by 2050. This legislation pre-dates - and currently falls short of the requirements of - the Paris Agreement. Progress towards this legislated target is supported by a series of 'carbon budgets' that become more challenging as the target date approaches (Committee on Climate Change, 2014).

The UK construction industry influences almost 47% of UK emissions of carbon dioxide (CO<sub>2</sub>), a key GHG. It is, therefore, important to engage the construction industry to ensure that successive GHG budgets are met. In particular, 8% of total UK CO<sub>2</sub> emissions relate to the GHG emitted in the extraction, production, transport, construction, maintenance, repair and end-of-life of construction material, termed 'embodied GHG' (BIS, 2010). Embodied GHG have been estimated to account for anything from 3% to 80% of whole life GHG emissions in UK buildings (Ibn-Mohammed et al., 2013). As buildings' operational GHG (the GHG emitted in the operation of buildings) fall in line with regulations and grid-decarbonisation (Giesekam, Barrett and Taylor, 2016), embodied GHG will represent a larger proportion of the total life cycle GHG. While much research has been undertaken to describe how to reduce operational GHG, the area of embodied GHG has received relatively little attention.

In 2013, the UK Green Construction Board (UKGCB) produced a route map for the construction sector to reduce GHG emissions in line with the Climate Change Act (UKGCB, 2013). This route map indicates that to meet the requirements of the Act, embodied GHG in construction needs to fall by 39% by 2050 from 2010 levels – a time when construction output was still recovering from the market downturn. Giesekam et al. (2014), reviewing the UKGCB's approach to this calculation, suggest that the UKGCB had "*significantly underestimated the required reductions*" in embodied GHG. A recent scenario analysis has suggested that embodied GHG intensity in the production of the built environment must fall by up to 67% across all projects by 2027 for the UK to stay on track to meet its legislated targets (Giesekam, Barrett and Taylor, 2016). Indeed the government's own 'Clean Growth Strategy' (BEIS, 2017) shows that they currently expect to miss the 2027 fourth carbon budget target by around 6%, and the fifth (2032) by 9.7% notwithstanding the currently described policies. Developments since the production of the UKGCB route map indicate that a conservative industry is struggling to de-couple construction output and embodied GHG. Embodied GHG is still seen to be increasing broadly in line with construction activity (Giesekam et al., 2014; Steele, Hurst and Giesekam, 2015; Giesekam, Barrett and Taylor, 2016). To provoke action towards the reduction of embodied GHG, an intermediate construction industry strategy reaching to 2025 has been launched (HMG, 2013b), and this has recently been bolstered by the UK Government's Industrial Strategy for the Construction Sector (HMG, 2018). These strategies challenge construction industry actors to work towards an emissions reduction of 50% by 2025. They remain silent on whether this reduction should come from operational or embodied GHG. While the UKGCB route map offers a path to the supply side reduction of embodied GHG, neither the route map nor the Industrial Strategy make proposals to influence the demand for NMS. It is considered to be highly unlikely that the industry can meet its GHG reduction targets without significant reductions in embodied GHG (Giesekam, Tingley and Cotton, 2018). Indeed, without a strong GHG-pricing signal to influence demand, there is little short-term economic incentive to make changes (Lehne and Preston, 2018 and Appendix A).

The UK is currently a net importer of £9bn of construction materials, and employs approximately 9% of Great Britain's total workers (ONS, 2017). Without action promoting embodied GHG

reductions on construction projects, the industry may have to import construction materials from countries with lower GHG reduction targets, or more (GHG) efficient production techniques. Such an increase in imports is contrary to the aspirations of the UK construction industry for a 50% reduction in the trade gap between total exports and total imports for construction products and materials by 2025 (HMG, 2013b). Further, significant deterioration in these figures could have significant macroeconomic impacts. Incremental reductions in embodied GHG resulting from the optimisation of the existing dominant material solutions (DMS), for example, concrete and steel in terms of super structure, are possible. However, while these incremental reductions are necessary, thermodynamic limits to the production of the DMS mean they are insufficient to deliver all of the embodied GHG reductions implied by the Climate Change Act (Allwood et al., 2012; BEIS and MPA, 2017). Therefore, if construction output and domestic material production levels are to be maintained or increased, the required emissions reductions can only be achieved by changing how the built environment is produced, maintained and re-used. This will require the use of a range of NMS.

However, since the late 1970s, UK Government policy has largely been underpinned by an assumption that markets, rather than governments, are best placed to respond to challenges such as the need to develop and implement NMS (Adamson and Pollington, 2006; BIS, 2016). Those in industry are considered to have the creativity, data, resources and expertise to create the necessary new solutions in pursuit of competitive advantage. Therefore, government intervention to reduce embodied GHG through formal institutional change is assumed to be unlikely in the short term. This market-driven perspective presumes that the establishment of the long-term goals of the Climate Change Act and the associated medium-term carbon budgets are sufficient to drive behaviour change in industry towards them. There is some theory to support this approach. For example, industry network-based regulation is shown to develop in response to the threat of government regulation (Baldwin, Cave and Lodge, 2011). However, relying on the market to respond to such long-term objectives may not lead to the timely NMS implementation on individual projects. When viewed from the perspective of an individual project, there appears to be little incentive or imperative to address these 'long run' (Ive, 1995) issues (Appendix A provides a more in depth discussion). Further, self-interested organisations will typically lobby in their own interests to ensure that institutional change favours them (Adamson and Pollington, 2006 provide examples): there are significant political pressures seeking to repeal the Climate Change Act itself (Lockwood 2013).

There is a growing awareness of the importance of embodied GHG emissions for reducing the UK's total GHG emissions, with professional, industry and research bodies (for example RIBA, RICS, UKGBC, Chatham House) exploring the issues in the search for solutions. In response, individual material-producing sectors have begun to identify and communicate how their materials might help to move the industry towards the goals of reducing embodied GHG emissions (BEIS and MPA, 2017), however incrementally. Further, pockets of academia and industry are attempting to promote the use of new technologies in pursuit of reducing GHG



emissions (Satterfield et al., 2009; Abraham and Gundimeda, 2014; Watson, 2015; Jervis, Moxham and Meehan, 2016), but with limited success.

The industrial sponsors of this doctoral research, Useful Projects and Expedition Engineering recognise the pressing need to enhance GHG and resource efficiency on construction projects and are keen advocates of the use of NMS on construction projects. They have experienced the effects of material lock-in, and the intransigence in the industry to step away from tried and tested materials. Wanting to accelerate change in the construction industry, they established this research project to look again at the problem of NMS implementation on projects from the perspective of practice. This thesis presents the outcomes of the ensuing exploration.

#### **1.4 Research Aims and Objectives**

This practice-based study adopts the perspective of a construction consultant seeking to encourage NMS specification and implementation on construction projects on a case-by-case basis. The lack of recognised theoretical base for studying the built environment is considered to be limiting the development of construction management research (Koskela, 2008; Cloete, 2017). This research addresses this need.

The research, therefore, aims to contribute by the development of a novel morphogenetic, descriptive framework in which to locate specification decisions, and assess the decisions' conditioning structure and the resulting, elaborating, impacts. With this knowledge, case-appropriate interventions can be selected to promote NMS implementation on a project-by-project basis.

The supporting objectives are to:

- 1) Explore and synthesise existing intervention strategies promoting change in construction projects (Chapter 6).
- 2) Describe a context-sensitive framework within which specification decisions can be located (Chapters 7 and 8).
- 3) Analyse the NMS specification decision in light of this framework (Chapter 9).
- 4) Assess existing intervention strategies' capacity to address the elaborating impacts of NMS specification to promote NMS implementation on projects (Chapter 10).

#### **1.5 Scope of the Contribution to Knowledge**

The research explores the problem of NMS implementation from the perspective of the project's industrial sponsors, construction consultants seeking to promote low embodied GHG construction by introducing these novel material solutions ('NMS') on a project-by-project basis.

The geographical scope of the research has been limited so as to restrict the influence of differing socio-political contexts on the problem of NMS implementation. Differing socio-political contexts can lead to significantly different industry dynamics, promoting or hindering NMS specification and implementation (Hall and Soskice, 2001; Mikler and Harrison, 2012). As the

researcher and supervisory team are physically located in the UK, the research has focused primarily on the UK construction sector. Further, there are three broad categories of new construction projects that make up construction output: housing (38.1% in 2017), bespoke buildings (43.6%) and major infrastructure projects (18.3%) (ONS, 2018). The scope of this study has been limited to the study of bespoke buildings. This limitation arises primarily from the distinct nature of the design and delivery systems for housing and bespoke buildings. Volume housebuilders in the UK adopt a supply-led, process-based model of delivery in which a standard product is procured and produced at volume, with minor changes, by a repeat and knowledgeable client. Bespoke buildings, on the other hand are demand driven and created to meet the unique needs of a client and site. Such a tailored approach requires a context-specific response from the designers, and the consolidation of appropriate component and material solutions to deliver value to the client. Second, infrastructure projects are typically procured by regional or national governmental bodies. These clients have significantly longer and broader decision horizons than commercial enterprises and are subject to less immediate pressures.

It is intended that lessons from this study of bespoke buildings might be generalised to the housing and infrastructure sectors and other socio-economic contexts. The study also has implications for those looking to innovate more generally on construction projects, for policy and the wider investment community. These implications are discussed in Chapter 11.

## **1.6 Impact**

### **1.6.1 *Academic Contributions to Knowledge***

This research has contributed to the literature with an exploration of how barriers to the adoption of Cross-Laminated Timber in construction have been overcome (Jones et al., 2016), reproduced in Appendix F for reference. This thesis further contributes to knowledge of construction management by bringing fresh insight and understanding (Charmaz, 2006) to the problem of NMS implementation in construction through the development and application of a new middle-range model (Merton, 1968) of the construction project as decision set. The model provides researchers with a coordinated and systematic perspective of the project in which to locate future research.

### **1.6.2 *Industrial Impact***

It is intended that the project industrial sponsors will be able to use the contributions to knowledge made in this thesis, helping them to effect positive change in the construction industry on a project-by-project basis. Further, in addition to contributing to project outcomes in the industrial sponsors' office, the research has advanced understanding of the means and role of innovation in construction across the office. Findings from the research have also been disseminated to an industrial audience through trade articles (Jones, Martin and Winslow, 2017), and industry focused conference debates and presentations (Jones et al., 2017; e.g. Winslow et al., 2017).

## 1.7 Structure of the Thesis

This research explores the problem of limited NMS implementation on construction projects, re-examining the construction project and interventions to promote NMS implementation. Chapter 2 describes the search for and selection of an appropriate unit of analysis and theoretical lens through which to analyse the construction project. The NMS specification decision is identified as an appropriate, unabstracted, unit of analysis for the study. Exploring the influences on this specification decision led to the adoption of the sociological perspective of structure and agency as the study's theoretical lens. After an exploration of the main theoretical perspectives on structure and agency, Archer's (1995a) morphogenetic perspective is identified as being ideally suited to analysing the emergent nature of the construction project, permitting separate explorations of a decision's conditioning structure, and its elaborating impacts. A literature review indicated that the application of this morphogenetic perspective to an exploration of the construction project is novel.

It became clear during the study that if the research is to address the problem of NMS implementation, the broader project context could not be ignored (after Pettigrew and Whipp, 1991). As such, a multi-disciplinary approach to the complex practice-based problem was adopted, leading to the use of an abductive approach to theory development and the adoption of research methods from the social sciences (Bresnen, Goussevskaia and Swan, 2005a). This approach to theory development requires an early exploration of the critical realist research philosophy and constructivist grounded theory building methods adopted during this auto-ethnographic study. These are described in Chapters 3 and 4. In particular, Chapter 4 describes the interplay between literature and data supporting the thesis development.

This auto-ethnographic, abductive exploration of literature and data has lent itself to the presentation of insights through a series of discussions, each combining the relevant data and literature, describing the outcomes of the exploration. The decision to adopt this structure, while unusual, is intended to avoid undue repetition and aid the clarity of the thesis. Table 1-1, below, describes the lines of enquiry underpinning each chapter, locating the research objectives, and highlighting the literature / data nature of each chapter.

In this context, Chapter 5 summarises the data gathered during the project, highlighting the importance of both locating the specification decision in a complex and emergent model, and analysing its conditioning structure and elaborating impacts. Subsequently Chapters 6 and 7 provide a description of the auto-ethnographic exploration of the problem of NMS implementation on projects, beginning in Chapter 6 with a review and synthesis of interventions proposed in the literature to promote NMS implementation on construction projects in practice (Objective 1). The discussion highlights how, despite the availability of many possible interventions, the selection and application of appropriate interventions to promote NMS on projects by consultants can be hindered by the absence of a suitable descriptive framework within which to locate the specification decision. Such a framework should allow researchers to assess a decision's conditioning structure and elaborating impacts, facilitating the selection of

appropriate interventions. Combining empirical data and previous literature, Chapter 7 describes the search for a suitable framework, and tests previous models of the construction project from the literature against the requirements identified in Chapter 6. Finding no suitable model, Chapter 8 presents a new middle-range descriptive model of the construction project in which to locate the specification decision (Objective 2). The model conceives of the project as an array of elaborating decisions, resulting from the exercise of agency in the face of a conditioning structure, required to move the project from inception to completion.

Chapter 9 then provides a means by which the NMS specification decision can be assessed in the context of this descriptive model of the construction project (Objective 3). The chapter integrates data and literature to explore how a specification decision's conditioning structure and elaborating impacts provide the decision-maker with the capability, opportunity and motivation (after Michie, van Stralen and West, 2011) to implement NMS on a project. Together Chapters 8 and 9 describe the framework within which the specification decision can be located, and its conditioning structure and elaborating impacts can be assessed (Figure 1).

Chapter 10 then uses the framework developed in Chapters 8 and 9 to assess the interventions identified in Chapter 6 (Objective 4). Chapter 11 describes the implications of the study for policy, practice and educational establishments. Chapter 12 concludes, highlighting the contributions to knowledge, practical recommendations to accelerate the transition to a low embodied GHG built environment, and the need for further studies.

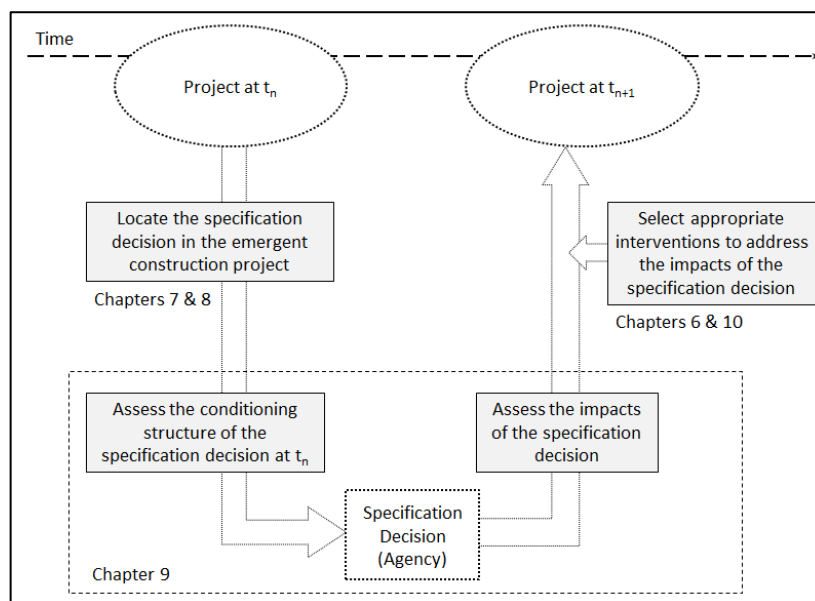


Figure 1 – Diagrammatic representation of the decision context explored in the thesis

Figure 1 provides a diagrammatic representation of the decision context explored in this thesis. The figure highlights how, in a dynamic and complex construction project, a specification decision is framed by a contingent, emergent conditioning structure. If this conditioning structure is to be assessed to determine whether it provides the decision-maker with the

capability, opportunity and motivation to specify an NMS, the specification decision must first be located.

Together, Figure 1 and Table 1-1 describe the structure for the review of the literature and data that support the development of a framework that allows the location and assessment of the specification decision, and the subsequent identification of case-appropriate interventions to promote NMS.

The Appendices to the thesis provide information, discussions and evidence supporting the narratives presented in the thesis. They have been removed from the main body of the text to improve the readability of the thesis.

Table 1-1 – Summary of thesis structure and lines of enquiry

Chapter	Questions considered	Locate / Assess	Research Objectives	Chapter Content
2	What is the nature of the problem of NMS implementation on projects? How should it be explored? What does previous research tell us about the construction project through the selected theoretical lens?	-	-	Literature
3	What are the researcher's philosophical, theoretical and methodological perspectives? What research methods should therefore be adopted? What does this mean for the research?	-	-	Literature
4	Data gathering	-	-	-
5	What do construction industry actors say about implementing innovations on construction projects? What are the characteristics of the industry that make researching construction challenging?	-	-	Data
6	What does previous research have to say about intervening to encourage NMS implementation? Are the interventions sufficient to ensure implementation on a case by case basis? What is stopping the selection of case specific interventions?	Assess	1	Discussion: Interplay of literature and data
7	Do existing descriptions of the construction project allow the location of the specification decision in its context?	Locate		
8	How can the complex, emergent and contingent construction project be described to allow the specification decision to be located? What impact does emergence have on the specification decision's conditioning structure?	Locate	2	
9	How can we influence specifying behaviour? How can actors analyse the conditioning structure of a specification decision? What are the elaborating impacts of specifying an NMS? What influence does an NMS have on the implementation decision? What does this mean for the resources allocated to a project?	Assess	3	
10	How do the interventions identified in the research influence the NMS specification decision? What does this tell us about intervening on projects to promote NMS implementation?	Locate and Assess	4	
11	What are the implications of this research for education, policy and practice?	-		
12	Concludes			

## 2 Researching Construction Projects

*"[The construction industry] thinks of the long run, not so much as a time at which 'we are all dead', but as that period that never becomes the present, and can therefore be ignored."*

*Ive, 1995*

### 2.1 Studying Construction Projects – Selecting a Unit of Analysis

#### 2.1.1 Reducing Abstraction to Identify a Suitable Unit of Analysis

During the research it became clear that when discussing the implementation of innovations on construction projects, either in academia or practice, there is a tendency to conflate, or abstract concepts. It is typical to talk of 'construction', 'designers' and 'buildings' as unified wholes, and the direction of innovation as a settled matter. By generalising the activity and minutia that make up these high level abstractions (Suhr, 1999), the grain of the industry is lost. The resulting discussions often ignore the fragmented structure of the industry (e.g. Baiden, Price and Dainty, 2006), in terms of its product (volume or bespoke production), the participants in the delivery process, and the reasons for innovating.

Buildings can be distinguished between housing, offices, factories, warehouses, schools, hospitals, etc.. Further, the location of the building plays a part in its definition: desert conditions should lead to a significantly different outcome from building in the centre of London. Weather and usage patterns, regulations, context, ground conditions, all lead to the need for distinct building performance attributes, with different challenges. So not only should a distinction be drawn by building type, but also by location, and intended use. Even where there are similarities between buildings with ostensibly the same function, and location – offices in a city, for example – they will typically be made differently – the Leadenhall building in the City of London has been constructed and performs differently from its contemporary neighbour at 20 Fenchurch Street. So it is possible to talk about specific buildings, and within those buildings, how the different elements, components, and the materials and products selected influence the performance attributes required. Thus the idea of a building is a high order abstraction (after Suhr, 1999). The level of abstraction can be reduced by describing the performances required of the building, element, component, etc.. However, a suitable low-level description of a building is only available once the necessary component or material specification decisions have been made. Similarly, the people involved in making a building include the clients in their multivariate forms (Boyd and Chinyio, 2006), their financiers and shareholders, the users, architects, acousticians, structural engineers, contractors, building regulators, materials providers, ecology consultants, sub-contractors, labourers, plant operatives, etc.. The list can seem endless. In the same way that a building is made up of its parts, it is not 'the industry' that performs these roles, but individuals, often in companies. The same abstraction can be seen in the descriptions of 'sustainability' and sustainable materials (Charlson, 2015). The literature

cautions against simple distinctions between client types of 'public' or 'private'. Each client will have distinctive roles, interests or value drivers (Healey, 1992). Indeed,

*"... behaviour should be understood as socially embedded within distinct markets, composed of complex networks of actors with their own distinct habits and practices framed by the prevailing rules and regulations of conduct."*

*Henneberry and Parris, 2013*

Suhr (1999) describes why these levels of abstraction matter in decision-making. The valid interpretations of the request for high level abstractions, such as 'a building' and resulting performances, are endless. What, for example, is a 'sustainable building' other than a coupled pair of high level abstractions? As a means of informing decisions relating to specifications on a building project, the abstractions render the description meaningless, and when a " ... *design question doesn't have a specific meaning, it does not have a specific answer*" (Suhr, 1999). The high order of abstraction has rendered making decisions about building performance problematic. Similarly, research at this level of abstraction can only provide limited insight for action in specific circumstances: the common failure to locate statements as being from the perspective of the client, the material producer, the builder or consultant limits the utility of research. Such oversimplification can lead to confusion and may lead to misapplied interventions. Indeed, in behaviour change intervention design, clarity over both object and context definition are considered to be critical. The construction design development process can be seen as a process of reducing the levels of abstraction so that individual performance specifications can be created by the project team.

In such a complex and context-dependent environment, it is essential that an appropriate unit of analysis is selected and articulated. However, determining the units of analysis in the investigation of NMS implementation is complicated by this same fragmentation and abstraction. Others, such as Dickinson et al. (2005) and Bygballe et al. (2013), have previously described the various units of analysis adopted in the construction management and innovation literatures as: industry; firm or multi-project organisation; project; individual; product; client; transaction; supply chain; social network; or multiple, covering several of these. They further highlight the need for analysis by construction sector; and by whether research focuses on the determinants, the diffusion or the process of innovation. Blayse and Manley (2004) review the units of analysis through their influences on an innovation's diffusion, specifically: the clusters of clients and manufacturers; the structure of production; relationships between individuals, firms within the industry and between the industry and external parties; procurement systems; regulations/standards; and the nature and quality of organisational resources. These layers of technology innovation systems (Hekkert et al., 2011) add further complexity to the research space.

Figure 2 shows the nested contexts that have multiple and varying influences upon the project and project participants. Each level of this context will influence the political, economic, social,



technological, legal (Boyd and Chinyio, 2006) and environmental (PESTLE) setting of the project. That is the project's institutional context. At the local level, the physical context of the development site also influences project decisions. Further, the project itself is typically created by and from a number of Project-Based Organisations (PBOs) (Gann and Salter, 2000).

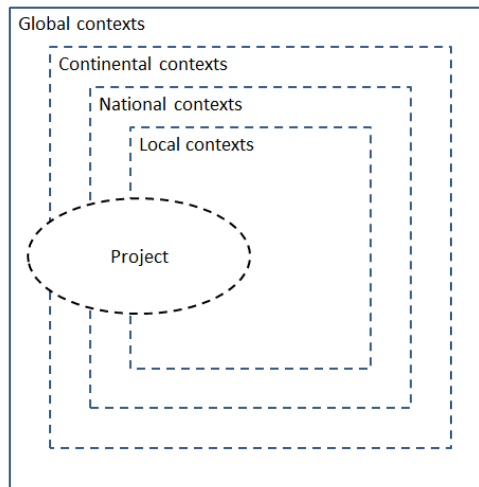


Figure 2 – A project's PESTLE context

PBOs are the organisations that come together to supply their own capabilities and resources to a project, such as architects, clients, engineers, contractors and sub-contractors (Figure 3). Project structures using PBOs are well suited to addressing changing client needs, integrating the different types of knowledge and skill required to deliver a construction project, and coping with complex project risks and uncertainties (Hobday, 2000).

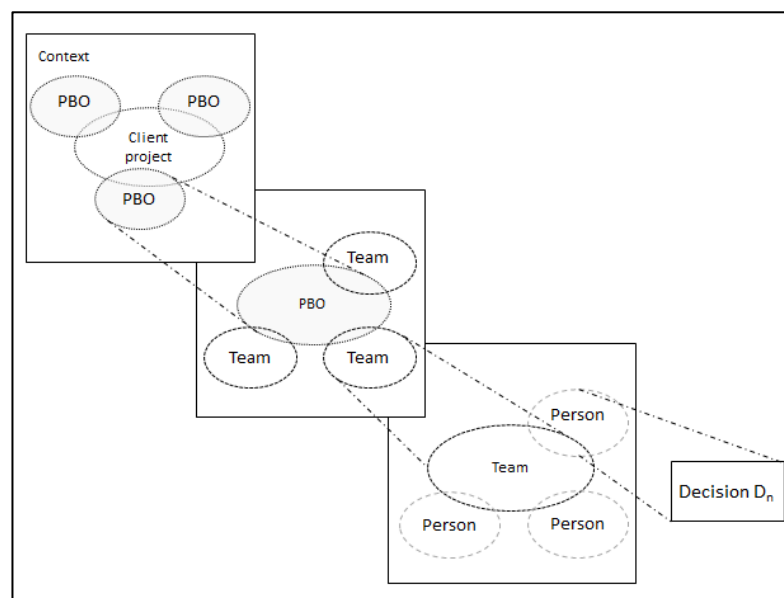


Figure 3 – Nested project and project-based organisation (PBO) structure.

The interaction of each of the elements indicates that actors have interests beyond the immediate scope. Each PBO has its own stakeholders, and teams, each with their own requirements of a project. Within these teams, there are usually additional hierarchies reflecting the seniority and experience of individuals, who will have their own objectives for working on a project. It should

be noted that due to its position at the head of the project, the client can be considered to be a special case of PBO.

This analytical complexity is overlaid onto a 'hypercube' of innovation (Afuah and Bahram, 1995), where new technologies such as NMS might be considered incremental to one of the many project participants, but radical or disruptive to another (Henderson and Clark, 1990; van Bueren and Broekmans, 2013). Due to this complexity, the construction project has been described as a complex adaptive system with emergent properties (Bertelsen, 2004). Further, these complex systems are open (Green, 2011), and dynamic. That is, they are not readily susceptible to analysis in aggregate. This immense complexity demands clarity in the definition of an appropriate unit of analysis, and in the location of research and interventions promoting the use of NMS on a project.

Any search for a dependent variable in such an open, multi-party, complex and dynamic system requires that system to be artificially closed, and thereby fixed. However, drawing a system boundary around any one level of the analysis in this nested, open system precludes consideration of the impact of other, potentially critical, contextual factors on the unit of analysis (Archer, 1995a; Engwall, 2003). Any analysis in artificially closed systems is necessarily incomplete. Exploring correlations between, for example, a PBO's size or ownership and its propensity to innovate (e.g. Hadjimanolis, 2000), precludes consideration of wider influences – such as regulation, country of residence, structure or culture – on that organisation (Reichstein, Salter and Gann, 2005). Further, it is argued that quantitative approaches to the study of construction management can inform understanding of what the industry does, but are less capable of articulating why, or how it does so (Harty, 2008).

This points towards a need for a contingency-based approach to the identification of interventions that promote NMS specification on a project-by-project basis (cf. Balachandra and Friar, 1997; Blindenbach-Driessen and van den Ende, 2006). That is, the appropriate intervention will depend upon the specific context of the project under review (Fernie and Thorpe, 2007). These circumstances will be similar across projects, but in each case, unique.

One unit of analysis that has been identified as being suitable for exploring construction management research is the adoption transaction itself. That is, the ultimate transaction to incorporate an NMS into a project. Indeed, Transaction Cost Economics (TCE) (Williamson, 2008) has previously been adopted to explore the construction project and has provided much welcome granularity to the construction management debate (Winch, 1989). TCE can be used to explore both the reasons for the existence of externalities (Dahlman, 1979) and the implementation of innovations in construction required to address them (Qian, Chan and Choy, 2013; Qian, Chan and Khalid, 2015). However, while adding insight, TCE is concerned primarily with identifying the efficient boundary of organisations faced with the 'make or buy' decision (Winch, 1989). As such, exploring the NMS adoption transaction and the associated transaction costs does not, of itself, account for the impact of the principal / agent separation of

decision-making in a multi-party project organisation, for instance, nor the influence of value judgments and organisational culture on decisions. While TCE provides helpful insights to the problem of NMS implementation on projects, it addresses only part of the challenge. TCE does, however, point towards the importance of a deeper exploration of the NMS specification *decision*, rather than the adoption transaction.

### **2.1.2 Specification Decision as a Dynamic Unit of Analysis**

Abstractions beyond the individual specification decision necessarily render any analysis incomplete. By focusing on aggregate data or on confidence intervals, research continues this process of abstraction. A stock answer of “*it depends*” can be avoided by considering how individuals make specific decisions relating to low order abstractions. That is, by describing on what it depends. Accordingly, the appropriate unit of analysis for the research project is considered to be that which allows an exploration of the lowest level of abstraction capable of analysis; the specification decision. This decision is typically made by an individual decision-maker, but may result from a consensus based view from a broader group of individuals. Consideration of the group dynamics that lead to decisions in these larger groups are, however, beyond the scope of this thesis. The individual or group making the specification decision is described here as the decision-making unit (DMU). However, the specification decision is not the one-time, static decision event typically depicted in the literature, it is dynamic in nature and can involve many parties (Emmitt, 2006). On a given project, a specification decision might initially be made by an individual architecture student, sat at the lowest level of the nested project hierarchy (Figure 3<sup>1</sup>), and at any point during the project life cycle, influenced by their own unique decision context (Figure 2). However, this initial specification decision may be reviewed, challenged, altered or rejected over the course of a project’s development as it passes through the project from the initial proposal through to final implementation in the completed project. By focusing on the dynamic specification decision rather than the transaction, research might transcend the organisational boundaries of the complex, dynamic, multi-party and open construction project. This analytical clarity allows an analysis of the problem of NMS specification to be located and considered at any point in the appropriate domains of context, PBO or decision (after Pettigrew and Whipp, 1991). The influences on and impacts of the specification decision can then be explored in detail.

Having identified an appropriate unit of analysis, the next section explores briefly the specification decision and introduces the notion of ‘solution spaces’ that has been used to explore the construction project in the research.

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<sup>1</sup> The PBO may also be located in a supply chain structure that will influence decision-making. The supply chain has been omitted from Figure 3 for clarity.

### 2.1.3 Conception of the Novel Material Solution (NMS) Specification Decision

Descriptive models of decision-making attempt to describe how decisions are actually made in the real world. A suitable descriptive model of the construction project is critical if research is to influence real-world decisions towards NMS specification. As Winch and Carr describe in the context of business process reviews:

*“... unless the process of change ... starts from a clear understanding of the current situation ... it is almost certain to fail.”*

*Winch and Carr, 2001*

This thesis conceives of the specification decision context perceived by an individual decision-maker as forming a ‘solution space’ (Figure 4) located at the lowest level of the decision hierarchy described in Figure 3. This decision context is informed by the PESTLE context within which both project and PBOs exist, and the decision-maker’s own values, knowledge and experience. The decision solution space so defined, also described as a feasible region or operating window in other fields, contains the potential solutions for a decision of which the decision-maker is aware, and that meet their decision objectives. From these possible solutions, a DMU will typically select an acceptable, rather than optimal, option. Figure 4 shows a 2-dimensional representation of such a solution space, constrained by the decision context, client, and the DMU’s own performance constraints.

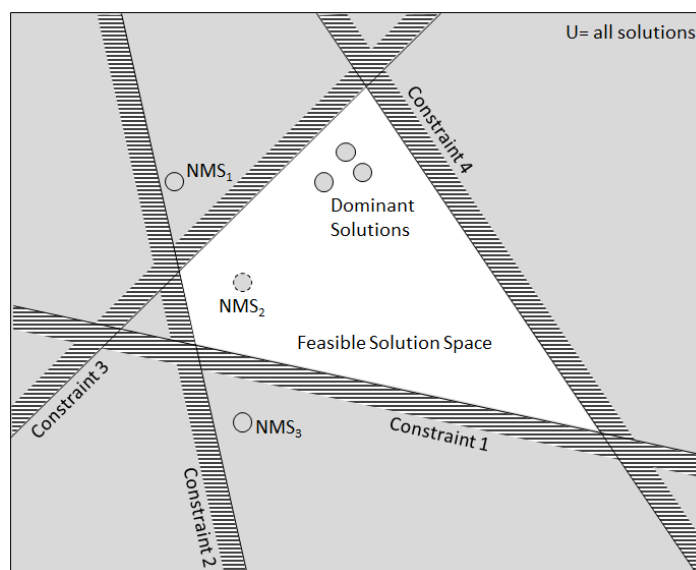


Figure 4 – 2D illustration of a solution space with 4 constraints

This shows how constraints can lead to the exclusion of NMS from a specification decision ( $NMS_1$ ,  $NMS_3$ ); or that a lack of awareness of a solution ( $NMS_2$  - dashed) might preclude a particular solution from consideration. To be clear, the solution space is not proposed here as a formal construct from which a decision-maker selects options, but merely a metaphor for the structuring of the specification problem in an individual’s mind. A related concept of a ‘choice model of design’ was identified towards the end of the writing process in the design studies literature (Rapoport 1976). Rapoport saw the concept as ‘fundamental to any understanding of

the environment'. However, his model was used to describe the influence of culture on the shaping of the built form by excluding certain choices from the solution space, that is, providing the cultural structuring of the decision. Rapoport's chapter reinforces the view adopted here that understanding the project as a set of decisions is the appropriate means of analysis.

If a decision were otherwise unconstrained, an individual would bring their own criteria to bear onto a specification decision, shaping the solution space for a given decision to reflect their own requirements. However, decision-makers may also choose to address some, or all, of the constraints imposed by the project context, or client objectives into their decision-making, for example, the need to minimise cost or risk. In doing so, they further constrain their personal solution space for that decision, omitting solutions that they perceive to be more costly or risky than the dominant solutions. This can lead to a rational inattention (Sims, 2003; Wiederholt, 2010) towards an NMS that might otherwise be suitable (Appendix A). This rational inattention to alternative solutions suggests that organisations focused on profits may continue to use the same materials, as they ration the use of limited resources (time) in the gathering of new material information.

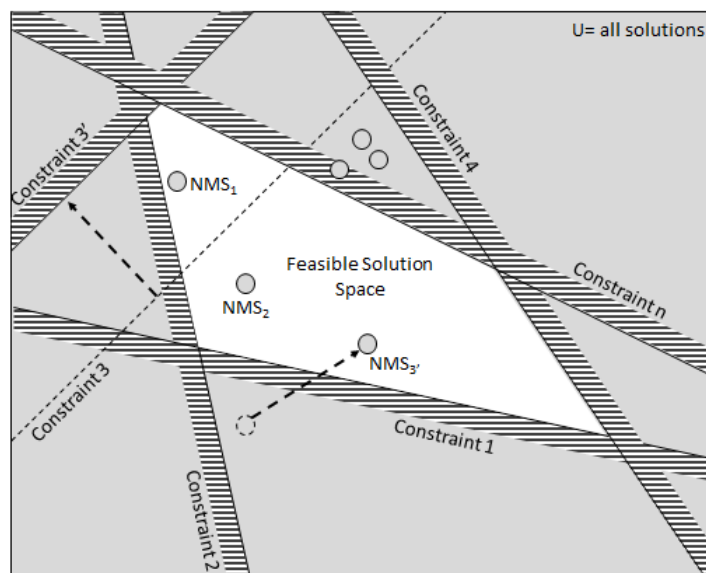


Figure 5 – Amended solution space with n-constraints

The introduction of new constraints, or the flexing of existing constraints, changes the shape of an individual's solution space for a given decision (Figure 5). These changes may alter the number of solutions available to a specifier, or may define a solution space in which the decision-maker lacks knowledge of any acceptable solutions. Should a specifier ignore these new constraints on the solution space, their initial specification proposals are likely to be moderated or sanctioned as the project proceeds. Barriers to the decision may also be presented. Further, solutions may be augmented or modified to bring them in to the decision solution space, for example, through subsidy or technical enhancement ( $NMS_3'$ ).

Solutions spaces describe the conditioning structure for a given decision. Accordingly, their study is important in pursuit of an understanding of how they influence the NMS specification decision.

## **2.2 Theoretical Lens**

*“The agency of actors, and any constraints to action should be better understood so that additional actions can be identified ...”*

*Roelich and Gieseckam, 2018*

### **2.2.1 Structure and Agency**

Section 2.1.3 has described how decision-makers exercise their agency in the face of a conditioning structure, the solution space, from which they select a preferred option. The problem of NMS specification can thus be conceived as one of structure and agency, the central concern of theorising on the nature of human interactions in society (Archer, 2000). However, sociologists adopting a structure / agency perspective of decision-making and behaviour take differing positions as to the relative importance of structural influences on individual agency and vice versa. The following sections explore briefly the main theoretical positions on this key structure / agency question.

#### **2.2.2 Structuralism – Structure as Antecedent**

Structuralists, or collectivists (Archer, 1995c), hold that a decision's structure precedes and guides the actions of the individual. Adopting a structuralist perspective leads researchers to focus on the effects of structural changes on aggregated data sets, such as populations, as a group (crime statistics, school attendance rates, etc.). The activity of the collective is presumed to be a simple aggregation of the behaviours of the individuals. Taking this position to its limits, individuals are left with no agency, they become 'inert' (Archer, 1995a) and bound to operate solely within existing structures. Further, considering the problem solely from the perspective of the aggregate means that the individual can play no part in any solution to societal problems, leading to social theories being advanced only in holistic terms. Accordingly, the structuralist perspective has limited power to explain the 'surprise' of NMS specification on a project.

#### **2.2.3 Individualism – Agency as Antecedent**

With individualism, individual behaviours and interactions are considered to lead to the development of social structure. Individualist writers (after Weber, 1964) observe the behaviour of individual agents, and extrapolate these to a wider population. As with the collectivist approach, individualism proposes a one directional influence, but in this case, the role of social structure is left inert. This view ignores the influence that rules, laws and social norms can have on the individual's exercise of agency.

#### 2.2.4 Structuration – Conflation of Structure and Agency

Recognising the limits of these two extreme theoretical positions, Anthony Giddens (1984) introduced structuration theory as a way to articulate the relationship between structure and agency. Giddens describes structure as the constraining influence of normative (behavioural) and interpretative (cognitive) rules and resources on the decisions and actions of individuals, within which actors exercise their agency (see also Appendix D on sense-making). The outcome of the interaction of structure and agency is seen in the performance of context specific, socially acceptable practices (Shove and Walker, 2010). While this description could equally apply to the decision-making processes described in Section 2.1.3, there is a key distinction: Giddens' structuration holds that both structure and agency reside within the individual (Elder-Vass, 2010). If that is so, neither can be demonstrated to dominate or influence behaviour, they are "*two sides of the same coin*" (Harty, 2008). So, while structuration theory deals adequately with reconciling structuralist and individualist perspectives of structure and agency, it does so by conflating them, making them inseparable in the individual (Archer, 1995a; Winch, 2018). Therefore, studies adopting structuration theory and other related practice based theories, including actor network theory, typically ignore notions of time, emergence and adaptation, each of which is important to the analysis of the dynamic construction project. This limitation means that structuration, and associated practice based theories are unable to address questions of 'when', regarding the circumstances under which structure shapes agency and agency shapes structure (Winch, 2018).

Due to this conflation, structuration theory is difficult to test empirically, limiting its applicability to that of a "*sensitizing [sic] concept [...]*" (Turner, 1986). Structuration theory is also critiqued for being conceptually imprecise, allowing the concepts to be adapted to fit the specifics of a researcher's circumstance (Tembo-Silungwe and Khatleli, 2018). Recognising these limitations Sujan et al., (2017) attempt to link structuration theory with Cultural History Activity Theory (CHAT), a view of psychology that explores how activity systems evolve over time. However, CHAT typically "*treats activity systems as reasonably well-bounded*" (Engeström, 2009). By imposing, or insisting upon, system boundaries on social phenomena, researchers lose sight of the wider societal context that individuals bring with them into a system. It is not feasible to disassociate the individual from these contexts. Attempts to do so are pre-determined to fail in their attempts to describe reality (Archer, 1995a).

This is not to say, however, that structuration theory and practice-based views are without merit. Of particular interest is Giddens' description of resources as "*the media through which power is exercised*" in the creation of structure. Individuals have varying degrees of control over the mobilisation of resources either within, and without their own organisation (Harty, 2008), limiting their ability to promote and accommodate change that requires additional resources. This points to the importance of the (non-) availability of resources for decision-makers, a theme that will be expanded on in Chapter 9.

## 2.2.5 The Realist Perspective of Structure and Agency

### 2.2.5.1 Analytical Dualism and the Morphogenesis of Agency

Adopting a critical realist ontology, Archer (1995a) rejects Giddens' conflationary response as unsuitable for the development of a strong realist social ontology. Her response, analytical dualism, highlights the evolutionary nature of agency and draws a clear distinction between structure, agency, and their interaction over time by way of emergent properties shaping both. Structure, she argues, represents time-specific configurations of social and cultural conditions brought about by the past interplay between structure and agency over time.

Archer adopts the terms 'morphogenesis' and 'morphostasis' from the biological sciences to highlight how, *"in the temporal process of acting, actors either reproduce or alter [...] the structural circumstances that originally bound them"* (Porpora, 2016). Morphogenesis relates to evolutionary changes in the structure of systems brought about by agent behaviour; morphostasis, on the other hand, describes the situation when an existing structure is reinforced. It is through such evolutionary processes (including those processes described by Nelson and Winter (Nelson and Winter, 1982), Kelly (2003) and Wieck (1995)) that the construction industry has reached material lock-in.

Archer (1995a) argues that some degree of structure necessarily pre-dates the actions that lead to a structure's reproduction or transformation; and that structural elaboration must post-date the exercise of agency. If realists are to adequately describe what happens in a society, then it becomes necessary to adopt a position of analytical dualism – an exploration of both structure and agency – along with the emergent properties influencing them both. Archer states:

*"Because the social world is made up ... of 'structures' and of 'agents' and because these belong to different strata [of reality], there is no question of reducing one to the other, or of eliding the two as there is every reason for exploring the interplay between them".*

Archer, 1995

In a rare empirical paper on morphogenetic change outside of the natural sciences, Mirani (2013) describes the morphogenetic cycle in the context of an offshoring process of IT services, using interviews and a longitudinal case study. He describes organisational change over the three phases of the morphogenetic change process; structural conditioning, social interaction, and structural elaboration. That is, agency (interaction) is exercised in the context of a (conditioning) structure that influences the goals and objectives of the decision-maker. Those interactions can cause both structure and agency to be reproduced or changed (elaboration) along with the associated DMU goals. While the morphogenetic approach has been subject to some philosophical and practical criticism (debated in Eren, 2016) Mirani's (2013) work shows that a morphogenetic lens can provide rich insights that might be overlooked by the relatively



static structuration and practice theories. Accordingly, the morphogenetic lens has been adopted as being suitable for this study.

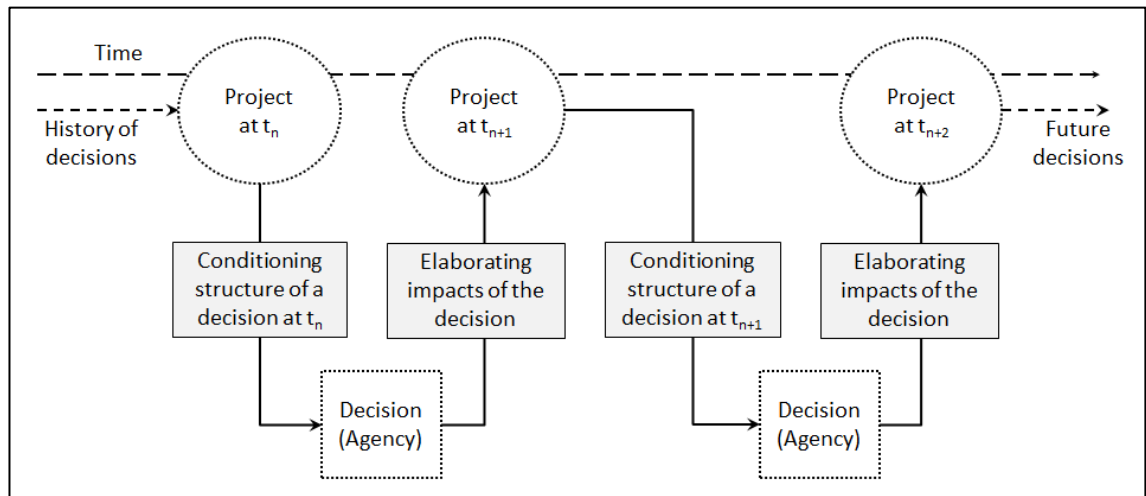


Figure 6 – The morphogenesis of agency in a construction project

A parallel can be drawn between this morphogenetic process of structural change and the emergent construction project development process (Figure 6). During project delivery, decisions are made in the face of earlier constraining (conditioning) decisions and assumptions; in turn, these decisions further elaborate the structures facing subsequent decisions (Archer, 1969). This process of structure formation and elaboration during the construction project development process lies at the heart of this thesis, and will be described more fully in Section 8.6.

Maintaining the analytical distinction between the exercise of agency in the face of conditioning structures, and resulting emergent properties of both allows for a better defined exploration of the NMS specification decision and the resulting elaboration than Giddens' approach, 'where structures are only 'instantiated' when agency is actively deployed' (Mollinga, 2014). It is notable, however, that Mirani's (2013) analysis stops at the level of the organisational interaction with the process of change, omitting consideration of individual agency.

This position adopts the simplifying assumption that an individual's actions entirely and only reflect their host organisation's objectives (after Simon, 1957), an unhelpful abstraction. If a model is to be useful, it should address the role of the biased, boundedly rational, satisficing individual in the context of the 'intendedly rational' organisation (Simon, 1955) operating in a dynamic project and institutional framework. It is clear that individuals continue to – or, at least, attempt to – exercise their agency within organisational contexts, and so research should extend to incorporate the role of individuals. Indeed, in light of the need for clarity over both context and object of change, their inclusion makes for a more complete description of the problem of NMS specification and implementation on projects.

### 2.2.5.2 Conditioning Structure – Endowments and Performance Objectives

Giddens (1984) describes how structure is formed by ‘rules and resources’. Rules are described as relating “...on the one hand to the constitution of meaning, and on the other to the sanctioning of modes of social conduct”. Resources stem either “from control of material products or of aspects of the material world” (allocative resources), or from the co-ordination of the activity of human agents, (authoritative resources). While this description of structure “departs from any traditional sociological understanding of structure” (Porpora, 2013), it provides an image of decision-making that aligns with the notion of solution spaces, described above. Solution spaces are defined by rules or constraints relating to a decision, describing the acceptability or otherwise of particular outcomes. Porpora (2013), however, takes issue with Giddens’ reductivist position, insisting on the consideration of structure in a more typical form. This, they describe as the study of relations, in particular, the relations between agency, and the cultural and physical contexts in which it is exercised, and from which it is kept analytically separate. In keeping with the desire to avoid conflation and abstraction, this position is adopted here, with some further elaboration (Figure 7).

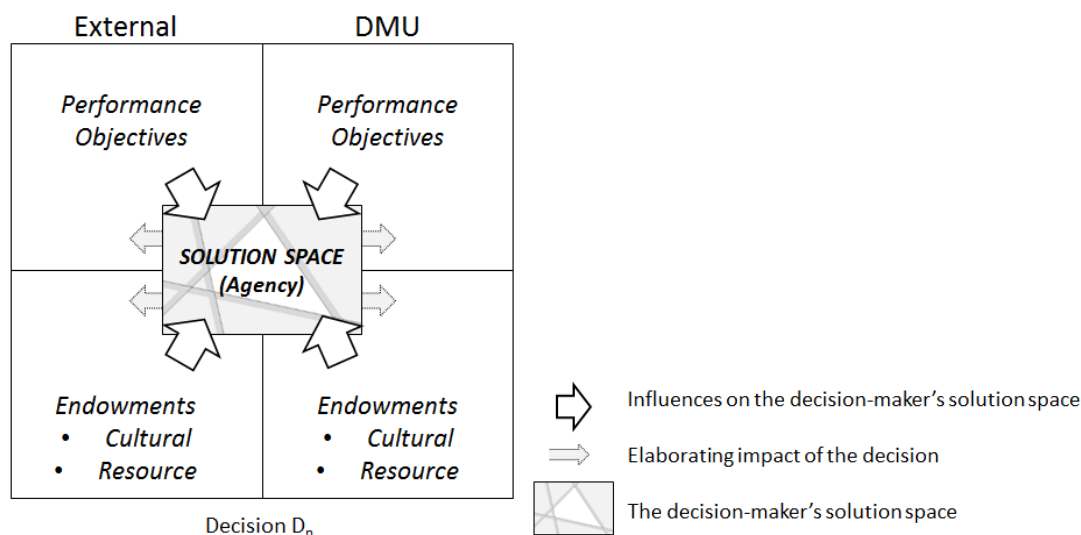


Figure 7 – The influence of the conditioning structure on a decision

The cultural context of a decision is taken to refer to the intangible aspects of structure relating to a decision-maker’s experiences, opportunities and outlook, incorporating historically contingent *endowments* in areas such as power and authority, economic system, position in a class structure, rights, legal context, and education and knowledge. Each of these endowments will influence their exercise of agency. The physical context relates to the resource endowment available to a decision-maker at a given moment, such as money or time. The two notions can overlap, for example in the context of control over resources. Identification of endowments at the point of decision is necessary to understand the influence of the elaborating impacts of the decision.

Porpora (2013) further highlights the absence of any discussion as to the role of motivations in changing structures in structuration theory. These motivations may be driven by individuals' concerns and value drivers, or their social positions (a behavioural exploration of motivations is provided by West and Brown, 2013). These motivations in a decision will be described here as a decision-maker's performance objectives that are brought to bear on a decision. When considering a decision in the construction project, the performance objectives of others will also need to be accommodated prior to a project's completion. From the perspective of the individual DMU, these are described as external performance objectives. These external performance objectives can incentivise decision-makers to innovate in pursuit of competitive advantage while at the same time constraining them. For example, a technology that saves time in the build phase of a project may require a substantial investment of limited time to master it.

### 2.2.5.3 *Elaborating Impacts of the Exercise of Agency*

Before continuing, it is worth reiterating the evolutionary nature of the decision's conditioning structure under the morphogenetic perspective. That is, a decision-maker's cultural and resource endowments at the point of decision are framed by all that has gone before and, through elaboration, influence that which follows. As Porpora describes, there exists:

*"... a dialectical relation between agency on the one hand and structural and cultural circumstances on the other. But to break into that circle and understand human action, we must begin with the circumstances, the actors' context."*

*Porpora, 2013*

Similarly, a decision-maker's performance objectives are influenced by the past, but also anticipate future outcomes, determined by their decision horizons (Hansson, 2005).

## 2.3 Literature Review: Structure and Agency in Construction

### 2.3.1 *Structure and Agency in the Construction Literature*

Despite the theoretical distinctions between Giddens' structuration theory and Archer's Morphogenesis of Agency, in practical terms, they both describe situations in which the decisions and subsequent actions of individuals is shaped by, and shapes, the context in which the decisions are taken. To inform the development of the research, a review of the related literature was undertaken to explore whether previous research had applied either perspective to the construction project. Table 2-1 below summarises a Scopus search (updated 21<sup>st</sup> March 2018) for prior literature.

Table 2-1 – Results of a search for construction related structure and agency literature

Search term	Results returned	Potentially applicable
"Structuration theory" AND construction	60	10

“Structuration theory” AND “construction project”	11	9
Morphogenesis AND construction	537	18
Morphogenesis AND “construction project”	142	7
“Structure and agency” AND construction	39	4
“Structure and agency” AND “construction project”	1	1

Structure and agency, in either guise, is relatively under-represented in the construction management literature. Eliminating duplicates led to the abstracts of 39 papers being reviewed. Of these, 15 proved to be potentially relevant to the research project. From this selection, 8 papers were classed as theoretical or methodological, 6 presented empirical studies, 3 were dynamic, exploring emergence (Mirani, 2013; Beverungen, 2014; Sujan et al., 2017), and 3 presented models of construction project, although each was through a structuration lens (Beverungen, 2014; Floricel et al., 2014; Sujan et al., 2017), and therefore inappropriate. Only two papers explored the real estate or construction industries through the lens of morphogenesis (Eren, 2016; Tian, Huang and Resconi, 2017). However both were theoretical papers, with Eren (2016) exploring the application of the morphogenetic approach to researching real estate agents, and Tian, Huang and Resconi (2017) arguing for an exploration of changes in risk using a computerised morphogenetic modelling approach. Other papers exploring similar computer based explorations of building form had previously been disregarded. No morphogenetic model of the construction project has been identified in these and related papers. Relevant insights from these and related studies that have not been previously incorporated, are discussed briefly below.

The earliest references identified in the search relating to construction projects are those from Bresnen et al. (2004, 2005a), who adopted Giddens’ theory of structuration as an heuristic tool to provide a more nuanced insight into the process of change in knowledge management practices in construction firms. Their studies highlight the importance of considering existing practices as embodiments of practical and historic knowledge, that is, cultural endowments, when proposing organisational change. These existing, locked-in, practices influence the challenges that organisations face when attempting to remove the agency of individuals who have previously had significant autonomy. This is particularly the case in the geographically dispersed construction industry, in which companies have typically grown through acquisition of local organisations (Smyth, 2018).

As a study using structuration theory, Bresnen et al.’s 2005 paper presents structure and agency as both fully formed, and static, limiting their utility for this study. Further, they adopt the single project organisation as the unit of analysis, and explore the agency of ‘management’ as a group (Bresnen, Goussevskaia and Swan, 2004, 2005a). This abstraction is limiting for the purposes of this study as it removes focus from the agency of the individual decision-maker. However, as the study explores the internal procedures of a single company, the use of the

project organisation as a unit of analysis has some merit. Ongoing entities will have established routines, rules and practices that employees are expected and trained to follow. However, this deterministic view sits uneasily with Bresnen et al.'s characterisation of the practices of project management as the outcome of "*a complex, and recursive, relationship between structural attributes and individual agency*" (Bresnen, Goussevskaja and Swan, 2005a). Unfortunately, this description is little explored, and only in the context of the individual PBO under study. This thesis takes the position that this characterisation can, and should, be extended to the wider project organisation to assist in the location and assessment of interventions to promote NMS specification on projects.

Beverungen (2014) explores this interplay between structure and agency in the process of organisational change, again in the context of an individual company, adopting an interpretation of structuration theory that allows for the exploration of emergence. Beverungen describes how performative aspects of business (practices) describe the work routines that are actually undertaken to achieve a particular end, while ostensive aspects denote the ideal (normative) forms of those routines. These ostensive aspects of business processes provide a structure to guide the performative, while the exercise of agency in the actual performance of organisational routines can lead to the reproduction or re-creation of the normative. Through this ongoing exchange, organisations will establish embedded practices, rules and routines. These routines will need to be disrupted for change to take place (cf. Bresnen 2005).

However, in contrast to ongoing organisations such as those studied by Beverungen, construction projects can be conceived of as being started anew each time. At the extreme, the construction project can be considered to be a *tabula rasa*. The processes necessary to complete a construction project have not yet been determined, let alone defined, or routinised. Project specific routines or rules must be established as the project unfolds. Some organisations that are repeat builders (Tzortzopoulos, Kagioglou and Treadaway, 2008) may already have many of these routines and rules defined to guide the development of new projects, allowing them to describe more clearly the structures within which the project development should proceed. Inexperienced clients do not have these routines and rules to draw upon. PBOs will bring their own routines, rules and practices to the project, creating structure and influencing their own decision-making on the project. This has implications for the solution spaces facing individuals from different PBOs.

In a theoretical paper, Bresnen (2007) reinforces the importance of studying the constraining role of industry and project context when researching practices. Unfortunately, the key examples cited by Bresnen in this paper (Bresnen et al., 2003; Bresnen, Goussevskaja and Swan, 2005a, 2005b; Bresnen, 2006) provide little insight as to how researchers might undertake such studies at both micro (decision) and macro (context) levels. Each example describes distinctions in structures that *might* influence outcomes, but, to paraphrase Winch (2018), there is no way of knowing about the pre-existing structures in each study that might have a greater influence on the eventual outcomes.

### **2.3.2 Structure and Agency in the Wider Development Process**

While the majority of papers reviewed study elements of the construction project itself, those projects exist in a broader development context. In the early 1990s, Healey produced a series of papers exploring structure and agency in the overarching development process (Healey and Barrett, 1990; Healey, 1991, 1992). In particular, Healey's 1992 study presents a model through which the overarching development process can be explored, with a focus on the key events, and agents' roles, and thereby agency, in the development. However, as an individual's role is made up of a changing sequence of decisions and related actions, the study's focus on roles represents an analytical abstraction, limiting the suitability of Healey's model for the purpose of locating decisions and assessing interventions. While Healey and Barrett (1990) discuss the importance of interventions influencing an agent's 'interests and strategies', there is no indication as to how these interventions might be located or assessed. Further, while the series of papers explore the hierarchical nature of the institutional context of the construction project in some depth, the levels of the individual decision receive relatively little attention. A review of the abstracts of all 371 citations of the three papers (Scopus, 19<sup>th</sup> March 2018) shows that while Healey's model has been extended to explore the project ecology (Henneberry and Parris, 2013), it has not been extended to incorporate decision-making at the development or construction project level.

In the papers reviewed, the various perspectives on structure and agency have been used simply as organising, or sensitising (Turner, 1986) heuristics allowing researchers to explore the broad contexts within which decision-makers exercise their agency, making general statements as to the influence that structure has on decisions. For example, Erin (2016) highlights how applying a morphogenetic analysis to the property market can be theoretically useful, but operationally challenging. On detailed review, the challenges encountered might have been addressed had Erin extended their analysis beyond the level of the organisation to the exercise of agency by the individual.

## **2.4 Conclusion**

A key challenge for the development of such a suitable theoretical base for construction management research is the linking of the nested, hierarchical structure with decision-making in the presence of emergence. The notion of solution spaces introduced in this chapter is intended to form a means by which the conditioning constraints of structure can be explored at the level of the individual decision, providing a means of analysing the question of NMS specification with the requisite degree of granularity.

The next chapters introduce the research philosophy, methodology and methods adopted in the search for a coordinated and systematic way to locate specification decisions and assess proposed interventions to influence them.

### 3 Research Philosophy and Methodology

#### 3.1 Introduction

The philosophical positioning of research describes the researcher's assumptions and beliefs about reality (ontology) and the development and acquisition of knowledge (epistemology). These beliefs shape research design, data collection and analysis and influence the potential contributions of the research (Saunders, Lewis and Thornhill, 2016).

This chapter describes the research philosophy underpinning this thesis, setting out the implications of adopting a critical realist ontology and a qualitative, auto-ethnographic approach to the development of an iterative, or constructivist grounded theory.

#### 3.2 Research Philosophy – Critical Realism

The ontological position adopted in research describes the perceived nature of truth underlying the researcher's conception of the world. Ontologies have historically been perceived from two broadly opposing perspectives: the objective (realist), or subjective (relativist, constructivist). The objectivist or realist perspective describes the world as real and existing independently of the observer. In the search for truth, objectivists typically propose that system boundaries be drawn around an isolated object of study to allow empirical testing, while controlling variables to identify causal mechanisms. The implicit assumption, challenged here, is that researchers are able to create an entirely closed system for examination. This is a particularly strong assumption in the social world of human activity. The extreme subjectivist view (also constructivist, relativist) is defined by two statements: 1) truth is relative to some frame of reference; and 2) there is no way of adjudicating as to which frame of reference is the right one through which to assess that truth (Krausz, 2010). That is, truth is a human construct, dependent upon the conceptual schema adopted by an individual.

These two extremes both contain limiting assumptions that undermine their ability to act as suitable starting points for research. In an attempt to reconcile these positions, Putnam describes that while an objective truth necessarily exists, there is no independent ('God's Eye') perspective of that truth, merely the points of view of actual people (Putnam, 1981). These points of view reflect an individual or group's conceptual, constructed scheme of the world, and their personal constructs (Kelly, 2003), informed by their interests, cultures and history. Similarly, critical realists assert the primacy of ontology (reality) arguing that the world continues to exist irrespective of the existence of humans (Mingers, Mutch and Willcocks, 2013):

*"We may understand global warming only via our own concepts, but, surely, if it is happening, global warming is an ontologically objective fact independent of how or even if we conceptualize it. Our understanding may be socially constructed but not the ontological reality itself."*

*Porpora, 2016*

This introduces the critical realist notion of a three tiered ontological perspective in which reality, manifestations of reality, and interpretations of it should all be considered independently. Further, critical realism recognises that knowledge is context-dependent (Reed, 2005), and epistemically relative (Bhaskar, 1989).

Critical realism is a meta-theoretical framework that seeks to reconcile the realist and relativist positions (Archer et al., 2016). Critical realism adopts the realist perspective that there is an independent, objective reality. However, it is critical of the position that observations can necessarily provide knowledge of that reality. Critical realists also accept the relativist position that individuals are influenced by their cultures, history and so on (Trochim, 2006). Therefore, critical realists accept that individuals will have their own truths and that their observations and views, including those of researchers, will be biased. In reconciling these two competing positions, Critical realism adopts a layered ontology with three 'domains' (Fairclough, 2005):

- 1) The domain of the real: The underlying and enduring causal structures and mechanisms of reality. These may or may not be observable;
- 2) The domain of the actual (observable): The 'actual' represents the visible manifestations of the real. This is the domain of events and processes, recordable by observation;
- 3) The domain of the empirical (observed and understood): The part of the real and actual domains experienced and interpreted by social actors.

Critical realists hold that objective reality is neither fixed nor empirically accessible, and that attempts to describe reality through observation of the empirical are fallible (see also Kuhn, 1970). Indeed, critical realists believe that all theories attempting to describe reality are also fallible. Section 3.8 discusses how research quality is achieved under these conditions.

A critical realist view of the question of NMS implementation in a construction project seeks to identify the underlying structures and causal mechanisms that influence the NMS specification decision through a reflexive, constructivist, process of abduction (Section 3.5). This is achieved through an exploration of the relationship between the real (the actual, underlying mechanisms) and the concepts formed of it through consideration of actors' experiences and researcher observation and reflection. The use of critical realism as an ontological position in the research has a number of implications which are now explored.

### **3.3 Epistemic Position – Epistemic Relativity**

Epistemology is the theory of human knowledge that questions, how we, as humans, can know things. It explores, *inter alia*, the criteria for judging the quality and adequacy of knowledge (Blaikie, 2007). Empiricists hold that knowledge can only be acquired through the experience of the senses and that those senses provide information about an objective reality. Kuhn's (1970) explorations of the history of scientific development shows the weaknesses in this proposition. By relying on a 'flat ontology' (Bhaskar, 2008), empiricists neglect the fact that the real causal



mechanisms may not be observable or knowable by an observer. In contrast, relativists hold that all knowledge is contextually constructed based on history, social setting, etc.. That is, entirely subjective.

Critical realism views humans as existing within inherently open and complex systems, and therefore accepts the relativist position of knowledge as subjective and context-dependent (Danermark, Ekstrom and Jakobsen, 2002). To the empiricist, this relativist positioning limits the ability to develop new knowledge through the uncovering of empirically described universal laws; however, not critical realists. The purpose of the critical realist research project is to create an explanatory or descriptive account of the research topic that provides a plausible causal model of the object of inquiry (Archer et al., 2016). Chapter 8 presents such a model, developed during the research.

### **3.4 Methodology – Autoethnography**

'Methodology' refers to the process, principles and procedures by which a researcher approaches problems and seeks answers (Bogdan and Taylor, 1975). Typically, a distinction is drawn between quantitative and qualitative methodologies with objectivists typically engaging with the former, constructivists the latter. While quantitative methodologies require rigidity of data, qualitative methodologies are designed to tolerate ambiguity and emergence in a world in which reality is socially constructed, complex and ever changing (Sloan and Bowe, 2014). The interpretive approach of much qualitative research is considered to be invalid by some positivist, empirically-based researchers. However, while a qualitative methodology requires a different set of methods from the quantitative – those with more explanatory power – they are considered as valid techniques by the wider research community (Miles, Huberman and Saldaña, 2014).

Critical realism promotes a methodological pluralism in which qualitative, quantitative or mixed methodologies are considered as suitable for research. The key decision for critical realist research is whether the methodology adopted is suitable for the phenomenon under review. This research project is exploring the decision-making around NMS specification and implementation. As such, the research seeks to develop a rich understanding of actor motivations for (non-)implementation in an open, complex and dynamic construction project. This requires an exploration of the views and beliefs of individuals operating in the context of organisations and projects. Accordingly, the research adopts a qualitative methodology – analytical autoethnography (Anderson, 2006; Ellis, Adams and Bochner, 2011; Grosse, 2018) – to review the challenges facing those seeking to promote the use of NMS on specific construction projects. Ethnography is an established research methodology, particularly in social science, with increasing use in construction industry research (Pink et al., 2010). It uses participatory research techniques that adapt to and evolve with the context (Pink, 2009; O'Reilly, 2012) to explore stakeholder roles and relationships. Ethnography as a technique has been used with grounded theory to respond to diverse academic and practice-based questions and is ideal for exploring NMS specification and implementation in a complex and dynamic construction environment. Combining ethnography with critical realism provides:

*“... a deeper understanding than subjectivism is capable of, one which is able to link the subjective understandings of individuals with the structural positions within which those individuals are located”*

*Edwards, O'Mahoney and Vincent, 2014*

Autoethnography is a form of action research (Herr and Anderson, 2014) in which the researcher explores a field, describing insights that *“stem from, or are made possible by, being part of a culture...”* (Ellis, Adams and Bochner, 2011). Active membership of the researched community means that researchers can experience similar opportunities and barriers to specifying NMS as other participants, increasing the opportunity for rich data gathering (Marvasti, 2013).

### **3.5 Implications for Theory Development**

The traditional scientific method is based on the deductive model of theory development. Beginning from statements which are held to be true, scientists make further, logically consistent, statements to reach a new proposition or theory that is suitable for empirical observation and testing. This deductive approach to theory building – moving from theory to data – relies on the possibility of falsification to establish scientific truth. That is, to be considered true, a proposition must be capable of being proven to be false (after Popper). In this mode, researchers use statistical correlation, representative samples and probability analyses to gain confidence that the theory under review is not false. However this depends upon the assumption that the initial statement is a true reflection of objective reality. Further, it requires that empirical observations are true and representative reflections of the actual events. These assumptions are challenged by critical realist researchers.

Inductive approaches to theory development attempt to build theory by drawing conclusions from observations of a population – moving from data to theory. Patterns are sought within observations of a population from which theories can be developed. However, such an inductive method *“runs the risk of becoming a rather trivial and shallow categorisation of data”* (Danermark, Ekstrom and Jakobsen, 2002). Indeed, similar reservations can be extended to inductive approaches adopted in studies on the barriers to use of NMS. For objectivist researchers, the key question in inductive research is whether the sample under review is statistically representative of a whole population. For the critical realist, however, the question is whether the patterns identified can guide the researcher to a plausible model of the phenomenon under investigation.

The deductive and inductive approaches to theory development are widely used in the social and natural sciences, and both have a place in critical realism. However, critical realists emphasise another approach to theory development that might also be adopted by researchers: abduction. Abduction, according to Peirce (1998), is the process of forming an explanatory hypothesis, being *“the only logical operation which introduces any new idea”*. While deduction *“proves that something must be [and] induction shows that something actually is operative,*

[a]bduction merely suggests that something may be” (Peirce, 1998 emphasis in original). Abduction begins with observation and proceeds with abstraction, moving to the development of a new conceptual framework within which to reinterpret and reconceive that observation (Danermark, Ekstrom and Jakobsen, 2002). More specifically, abduction:

*“..consists of assembling or discovering, on the basis of an interpretation of collected data, such combinations of features for which there is no appropriate explanation or rule in the store of knowledge that already exists.”*

*Reichertz, 2004*

The leap to a new interpretation, according to Peirce, is “*an act of insight*” that comes to us “*like a flash*” (Peirce, 1998 emphasis in original). While this may sit uneasily with positivists, positivism itself has little to say on the subject of theory development beyond logical consistency. Popper, the father of the deductive method, had little interest in how hypotheses were formed, merely with the quality of their testing (Blaikie, 2007). Through a focus on theory development and testing, critical realism attempts to provide an account of the whole research cycle (Bhaskar, 2014) rather than elements thereof. In the search for a suitable decision-based model of the construction project, abduction is a necessary step towards theory formation (Rahmani and Leifels, 2018). Merton’s (1968) middle-range theories are examples of abstractions brought about by abductive inference. The task of middle-range theorising begins from specific local-level problems and “*...asks what type of process have we encountered here and how can we explain the underlying dynamics?*”. In responding to these questions, researchers seek mechanisms that might account for what can be observed (Green and Schweber, 2008). Abduction involves developing theory that aims “*to provide causal explanation of what has not necessarily been empirically deduced or induced, but has been synthesised and inferred from available empirical data and related concepts*” (Kempster and Parry, 2014). Abduction, then, is the process of conceptual abstraction that allows the researcher to move from the observation of phenomena, using, in this case, ethnography, to the reconstruction of the basic account of how the observed social world works (Edwards, O’Mahoney and Vincent, 2014; Winch, 2018). In moving beyond subjectivist descriptions of events to postulate the underlying reasons for them, this abductive step in critical realist theorising, supported by rich observations of actors, is, necessarily, reflexive and constructivist. Ethnography is “*ideally suited to supporting this process*” (Edwards, O’Mahoney and Vincent, 2014), indeed, the “*full value of [...] ethnographic studies can only be realized if they are situated in their [...] contexts*” (*ibid.*). Critical realism provides the means by which to link the micro level data to the broader context.

Using abduction, a researcher follows a spiral movement between the literature and empirical observation to uncover regularities in the domain of the real (Belfrage and Hauf, 2017). This iterative development process has been adopted in this research project, and is described in Section 4.7 below.

### 3.6 Research Methods – Constructivist Grounded Theory

While a methodology describes the strategy, design or plan of action lying behind the choice and use of particular methods, the methods are the techniques and procedures used to gather and analyse data related to the research question (Crotty, 2003). In adopting a qualitative methodology to the research project, the broad methods available to the researcher are reduced to five (Wertz, 2011):

- Discourse analysis emphasises the importance of the role of language in constructing meaning. It explores how discourses construct or constitute social reality and social relations. The analysis undertaken can lie from a detailed deconstruction of a single text, through to theoretical abstractions about the nature of social practice gained from a wide review of a larger number of data points (Saunders, Lewis and Thornhill, 2016);
- Narrative research draws on literary theory to explore how speakers recount their experiences of a phenomenon through storytelling. These stories are then analysed and described using narrative devices such as plot, setting, activities and climax (Creswell, 2014). Here, the power of storytelling is used to disclose human meaning (Wertz, 2011);
- Phenomenological methods developed from the fields of philosophy and psychology aim to describe individuals' experiences of a phenomenon. This method uses "*the analysis of significant statements, the generation of meaning units, and the development of ... an essence description*" to create theories (Creswell, 2014). Essentially, this seeks to develop meaning-oriented descriptive knowledge;
- Intuitive inquiry allows the researcher a degree of freedom to pursue the research, 'incorporating researchers' intuitive, emotional and personal capacities' to foster "*personal and cultural transformation*" (Wertz, 2011); and
- Grounded theory, which is discussed further below.

The first three of these methods can provide useful insights for researchers. However, their focus on specific approaches to analysis – the use of language, literary theory and the phenomenological creation of meaning – were deemed to be limiting and inappropriate for the intended audience for the research: engineers and consultants. Similarly, intuitive inquiry was also judged to lack the structure that a typically quantitative audience might expect in a research project. A pragmatic decision was taken, therefore, to adopt a Grounded Theoretical method by which to explore and develop theory.

Grounded theory was introduced by Glaser & Strauss (1967) to provide a rigorous method for inductive research. This 'classical' grounded theory was developed from the objectivist tradition in which natural laws are deemed to be uncovered through a systematic review and coding of data. Since its introduction many variants of grounded theory have been established.

The original conception of grounded theory held that theory development should take place before engaging with the literature. The research process might then, it was asserted, remain unbiased by the preconceptions of the researcher and demonstrate validity and reliability.

Strauss and Corbin (1990) developed a more complex process for conducting grounded theory that moved the method further towards verification (Charmaz, 2006). They too adopted an objectivist approach, albeit with a recognition that researchers have an influence on the outcome of the process of theory development. Their response though was to find ways by which the impact of researcher influence might be removed in the grounded theory process (Charmaz, 2006). Due to their objectivist positioning, both 'classical' and 'Straussian' forms of grounded theory are considered incompatible with the relativist epistemology adopted in the research. Charmaz (2006), in describing a constructivist grounded theory, adopts the relativist position that theories and laws are not 'discovered', but constructed or developed by the researcher through interaction with the field of enquiry, in this case through abduction. Such theorising requires reflexivity on the part of the researcher. Both positions are compatible with the critical realist perspective adopted.

It is noted that several researchers have recently attempted to describe a grounded theory for use explicitly with critical realism – critical grounded theory. Their aim is to incorporate explicitly the critical realist requirement for abduction in the grounded theory process. These authors also embrace the need to engage with the wider industry and related literature during the theory development process to ensure fit and relevance (Oliver, 2012; Kempster and Parry, 2014; Belfrage and Hauf, 2017). However, Charmaz's description of the constructivist grounded theory development process as requiring "*playfulness*", "*openness to the unexpected*" and "*whimsy and wonder*" (Charmaz 2006) are judged to mirror Peirce's "*flashes of insight*". Therefore, constructivist grounded theory is considered to adequately describe the critical realist process of abduction that critical grounded theory is attempting to incorporate (see also Timmermans and Tavory, 2012). Further, Charmaz adopts the pragmatic position that literature may be reviewed during a research project because novice researchers are often required to engage with a wide range of literature to properly engage with the research area (Charmaz 2006, pp165-166). Indeed, the structure of the Engineering Doctorate requires that researchers complete academic modules during the course of their study and so interacting with related literature is unavoidable. Constructivist grounded theory is therefore considered to meet the needs of critical realism for theory development. Further, as constructivist grounded theory has already been adopted in many fields, including in recent doctoral theses in construction and construction project management (Mills, 2013; Watson, 2015), it is considered to be an appropriate method for this study.

The detailed process of constructivist grounded theory analysis is discussed below.

### **3.7 Constructivist Grounded Theory Data Gathering and Analysis**

#### **3.7.1 Data Gathering**

The practice-based nature of the Engineering Doctorate located the researcher within the environment that they sought to study, the construction industry. In such a data rich environment, learning and insight can arise from anywhere, and at any time. Accordingly,

throughout this research, Glaser's grounded theory dictum that "*All is Data*" (Glaser, 2007) has been adopted. This means that researchers are able to gather evidence from any source and should expose themselves to a wide range of opportunities to gather data (Thornberg and Charmaz, 2013). This could include formal research instruments such as case studies, interviews, action research and surveys, but evidence can also be obtained from informal sources, such as industry reports, conversations, presentations etc.. This is because these less formal data sources also shed light on how the problem of NMS implementation is considered by participants in the industry. The position is summarised by Glaser (2007):

*"The data is what it is, and the researcher collects, codes and analyzes [sic] exactly what he has [...]. There is no such thing as bias, or objective or subjective, interpreted or misinterpreted, etc. It is what the researcher is receiving (as a human being, which is inescapable)."*

Accordingly data has been gathered with both formal and informal instruments from multiple sources (Chapter 5 and Appendix B refer).

To understand a human-centred problem such as NMS specification and implementation, the researcher must understand the industrial context in which incidences of NMS implementation arise (extensive data). However, to identify causal mechanisms on a case by case basis, the researcher must gather rich (intensive) data. Rich data is so called as it should represent and "*reveal the complexities and the richness of what is being studied*" (Marx, 2008). The gathering and analysis of rich data allows researchers to move beyond the surface of a problem and to begin to understand the phenomena in more detail. Indeed, one of the main advantages of studying communities of practice and cases to gather rich data is:

*"... that they observe effects in real contexts, recognising that context is a powerful determinant of both causes and effects..."*

*Cohen et al., 2011*

This suggests an immersion with the subject under study, in this case the construction industry.

Creswell (2014) describes four basic types of data collection in qualitative studies:

#### *Observation*

Researchers take open-ended field notes on observed activities. The observer may "*engage in roles varying from non-participant to a complete participant*" (Creswell, 2014) while undertaking these observations.

#### *Interviews*

Interviews are undertaken to elicit rich data from participants either individually or in a group context. Interviews can be unstructured, semi-structured, or structured. Structured interviews are used to gather common information, but do not allow further exploration of the issues raised. Semi-structured interviews begin with specific questions, but allow researcher's latitude

to explore further issues of interest. Unstructured interviews allow a wider exploration of the subject under discussion, leading to the gathering of rich data by the researcher.

#### *Documentation Review*

The documents reviewed might be public documents, such as reports or news items, or private documents such as emails or memoranda.

#### *Audio and Visual Material Review*

Here the researcher explores photographs, web pages, videos, or social media text.

Each of these four data collection types were used during this research. The application of each is described in Chapter 4 below.

### **3.7.2 Data Analysis: Coding in Constructivist Grounded Theory Development**

The process of analysis and subsequent model formation in constructivist grounded theory begins with qualitative coding. Qualitative coding is the process by which the researcher reviews and categorises sections of the data gathered during research. This is at the heart of the distinction between inductive and deductive studies. In inductive studies, the codes are established from the data, in deductive studies, codes are imposed upon the data. Coding in constructivist grounded theory is the first step in moving beyond concrete statements in the data to making analytical interpretations (Charmaz, 2006). Coding typically takes place over two stages, initial (or open) coding and focused coding.

#### *3.7.2.1 Initial (Open) Coding*

This first round of coding is undertaken to discern similarities and differences between data. In an evolutionary development process, data is compared against other data, and then tested against emergent (proto-) theories (discussed further below). Coding proceeds by giving conceptual labels to sections of data and the grouping of related data together (Cho and Lee, 2014). Charmaz (2006) describes how this initial coding is used to “*mine early data for analytic ideas to pursue in further data collection and analysis*”. This initial coding can take place both informally during the process of data gathering and subsequently as the texts are analysed. The term ‘texts’ is used here in its widest sense, as anything presented for interpretation, including transcriptions of interviews, field notes, reports, observations or memos. The use of this initial coding process helps researchers create analytical categories and theories that necessarily have two of the criteria for grounded theoretical models: fit and relevance (Charmaz 2006).

#### *3.7.2.2 Focused and Theoretical Coding*

Focused coding is the process by which the researcher re-tests the data set with the most promising codes arising from the initial coding to synthesise the data gathered (Charmaz, 2006). These focused codes are more conceptual and selective than incident based coding and their development is part of the process of abstraction required to develop models

grounded in theory. This process of abstraction eventually leads to theoretical codes that enable the codes to be integrated into a theory. Figure 8 shows a diagrammatic representation of the grounded theory development process. For clarity, Figure 8 omits the feedback loops, testing and constant comparative process that continues throughout theory development.

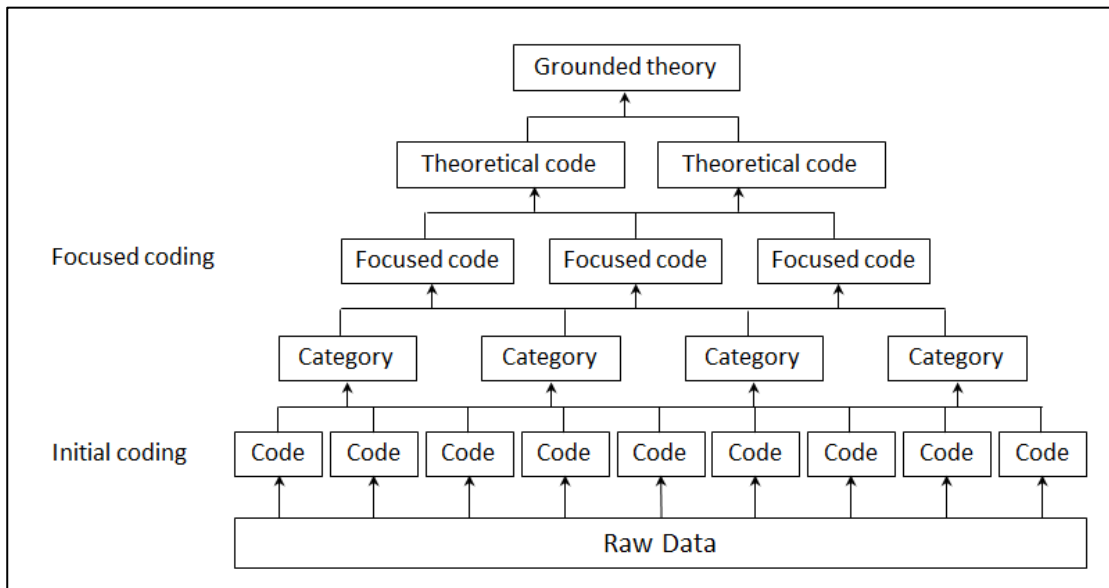


Figure 8 – Illustrative schema of grounded theory development

### 3.7.2.3 Constant Comparison and Theoretical sampling

Grounded theory is built upon two key concepts: constant comparison and theoretical sampling (Suddaby, 2006). Constant comparison is the process by which data are gathered and analysed concurrently against existing theoretical understandings. In this way, the researcher assesses the empirical evidence in front of them against the key theoretical constructs established to date. The data and constructs are tested for fit and relevance. The outcome of that comparison might be new theoretical insight. Theoretical sampling, then, directs the researcher to pursue these “*insights, hunches, [and] ‘Aha’ experiences*” to inform subsequent sample selection (Thornberg and Charmaz, 2013). Theoretical sampling aims to guide data gathering to ensure that the newly conceived theory is complete (Cutcliffe, 2000; Elliott and Lazenbatt, 2005). Sample selection is driven by emergent theory, and on the basis of the potential manifestation or representation of key theoretical constructs (Patton, 1990). Therefore, the research sample cannot be predetermined before the research begins (Elliott and Lazenbatt, 2005).

### 3.7.3 Data Analysis: Memo-writing

The process of initial coding is closely linked to the process of memo-writing, a key tool in theory development. Memos, in constructivist grounded theory, are summaries of emerging categories in which researchers analyse and explore their data throughout the research process. The memo-writing process is seen as critical to keeping the researcher engaged with the analysis, and encourages the abstraction of ideas (Charmaz, 2006).



These memos can take any form, including that of diagrams. Diagrams provide a visual representation of emergent categories and the relationships between them. Diagrams are, therefore, frequently used as an intrinsic part of the grounded theory method (Charmaz, 2006). This research has been developed primarily through the use of diagrammatic memo representation in the form of proto-theories. 'Proto-theory' is the term applied in this thesis to the interim theoretical constructs that were developed over the course of the project, against which emergent data were tested. Key stages of the evolution of these diagrams are presented in Appendix C.

### **3.8 Achieving Validity in Qualitative Research**

Reliability and validity are commonly accepted measures of quality for quantitative research projects. Reliability is a function of the repeatability of a research process. It indicates that the research design is consistent across researchers and projects, and will deliver the same outcomes when repeated (Creswell, 2014). Internal validity "*relates to whether the findings ... relate to and are caused by the phenomena under investigation and not other unaccounted for influences*" (Winter, 2000). External validity reflects the ability to generalise research findings to wider populations (Guest, MacQueen and Namey, 2012). To ensure reliability and validity, positivist, quantitative studies delimit and isolate variables, creating closed systems. Interpretative studies, on the other hand, explore complex, open and adaptive systems, with contingent outcomes (Winter, 2000). Demonstrating reliability and validity in qualitative studies presents challenges: It is clear that researcher interpretation is involved during non-deductive inferencing, and while processes might be repeatable, different researchers are unlikely to develop the same theories from a given set of data, and the data they receive may change. However, "*[r]eliability and validity are tools of an essentially positivist epistemology*" (Watling 1995, cited in Simco and Warin, 1997) sitting uncomfortably with subjectivist studies such as this one.

The validity of qualitative research is therefore judged on the 'soundness' (Guest, MacQueen and Namey, 2012) of the theories or models developed through the research process. This is judged on the fit and relevance of the model to the empirical data gathered, and the model's plausibility in describing the phenomenon under consideration. To enhance the validity of qualitative research, researchers are guided to use a selection of data collection techniques to "*touch at the core of what is going on*" (Greenhalgh and Taylor, 1997) and triangulate findings. Fusch and Ness (2015) suggest that researchers concern themselves with the collation of both rich (intensive) and thick (extensive) data. Further, studying many cases is crucial because researchers can become aware of their preconceptions about their topics and compare their theories and models to a wider range of situations (Charmaz, 2006). This research has addressed these differing data needs by undertaking unstructured and semi-structured interviews, project reviews, and by working on projects related to the problem space of construction, while at the same time interacting with the construction industry at events, presentations and meetings.

In addition to immersing oneself in the domain and seeking out many data points to enhance internal validity, Danermark et al. (2002) suggest the following techniques to enhance the quality of research, each of which have been adopted in this research.

#### *Studies of Pathological and Extreme Cases*

Reviewing cases in which the mechanisms under review are operating most clearly allows researchers to study and isolate the underlying mechanisms more readily. In this study, both extreme cases, where NMS have been implemented, and pathological cases, where implementation has not occurred, have been studied. Chapter 4 discusses case selection further.

#### *Comparative Case Studies*

Case studies allow researchers to explore similarities and contingent differences between examples to arrive at common, universal models.

#### *Social and Thought Experiments*

Simple (ethical) social experiments can be established to explore the fundamental assumptions that people make in their day to day lives that lead to identification of the preconditions for interaction. In other cases, where there are ethical considerations, thought experiments can be used to explore the notion of 'what would happen if...'. Often, it becomes unnecessary to actually carry out an experiment – the researcher can frequently imagine the consequences of breaking an expectation in a given situation. In doing so, the researcher "*can and should use experiences [...] acquired both in research practice and ordinary life*" (Danermark, Ekstrom and Jakobsen, 2002, p103).

#### *Counterfactual Thinking*

This is the application of experience and knowledge to think about what might be, rather than what is. In the case of research relating to barriers to implementation, for example, the researcher chose to see the reports not as barriers that are present, but as an absence of some enabling mechanism. This is discussed further in Section 4.8.

Data saturation is also important to ensure validity in qualitative research. However, there is "*no one-size-fits-all method to reach data saturation*" (Fusch and Ness, 2015, emphasis in original). A qualitative sample is considered large enough when additional examination yields no further useful information (data) towards theory development (Patton, 1990), that is "*when your data starts repeating, you have discovered most of what you can get*" (Schatz, 2003). Data saturation is contrasted with the related grounded theory concept of 'theoretical saturation'. This is the condition under which, new data, when reviewed, compared and suitably abstracted, fails to yield new theoretical insight.

Triangulation, the use of multiple sources of data, can go a long way towards achieving both data and theoretical saturation, indeed it is one method by which the validity of the study results are ensured (Dainty, Bagilhole and Neale, 1997). The next chapter describes the multiple sources of data used in this research.

In this research, saturation was considered to have been reached when an abstracted, parsimonious middle-range theory had been developed that adequately described the existing literature, the empirical evidence gathered and the author's experiences in the industry before and during the research project.

### **3.9 Implications for Findings**

Critical realism holds that attempts to describe an underlying reality from any research project, be it objectivist or relativist, are considered tentative, biased, and subject to replacement (Kuhn, 1970; Trochim, 2006; Blaikie, 2007). Critical realist theories and models are recognised as offering only provisional descriptions and are always open to revision and reformulation (Reed, 2005). Rather than contributing 'verified' knowledge, both critical realists and grounded theorists describe plausible accounts of phenomena as their primary contributions (Charmaz, 2006). These accounts are then suitable for further exploration and testing. The findings from this research, therefore, are presented as a plausible explanation of the underlying operations relating to NMS implementation on construction projects.

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## 4 Methods: Data Gathering, Analysis and Theory Formation

*“..theory-building in the built environment tends to be fragmented, under-resourced and explored from the limited perspectives of individual disciplines or interest groups within the construction/ property industry.”*

*Koskela 2008*

### 4.1 Overview of Project Development

Rather than identifying a gap in the literature to explore, this research problematises NMS implementation in construction (Sandberg and Alvesson, 2011), taking a new look at the challenges facing practitioners. In exploring the problem space, the research moved between practice-sourced data and the academic literature, integrating practical experience and relevant disciplinary views of the problem, challenging assumptions, and identifying limitations in the existing literature. This chapter sets out how the data was gathered and how it was used and analysed to produce the findings and theories presented in Chapters 6 to 10.

The research project was divided into two broad, overlapping, phases:

- The first phase, domain exploration, allowed the researcher to gain an understanding of the problem space, and to develop and explore initial theories about overcoming the challenges to NMS implementation.
- The second phase, problem exploration, developed the initial insights from the first phase, through a deeper exploration of the problem space. The process and end point of this second phase of research is presented in Chapters 6 to 10.

Abductive inference involves creating a preliminary (abductive) hypothesis as to the mechanisms at work in the research field, based on an interplay between the theories and data gathered to date (Timmermans and Tavory, 2012). The researcher began this study after several years of commercial experience, including time working in the construction industry. This experience informed an initial model of the problem of NMS implementation (proto-theory 1 in Appendix C). As the project proceeded, new data and literature were assimilated, analysed, and compared to the earlier proto-theories. In a morphogenetic process, extant proto-theories were either reinforced by the data / literature or updated to reflect new insights, a process of sense-making (Weick, 1995; Green, Kao and Larsen, 2010). This evolutionary development process continued until theoretical and data saturation was considered to have been achieved (Section 3.8) with the development of the middle-range theory presented in this thesis. Figure 9 provides a diagrammatic representation of this research development process.

### 4.2 Overview of Data Gathering

In this practice-based research project, the researcher interacted with construction industry participants, those in industry concerned with resource efficiency, and academics in related fields. This research therefore represents a form of ethnographic study (Section 3.4) in which

the research outputs are co-produced through a dynamic cooperation between practitioners and the researcher over time (Green, Kao and Larsen, 2010).

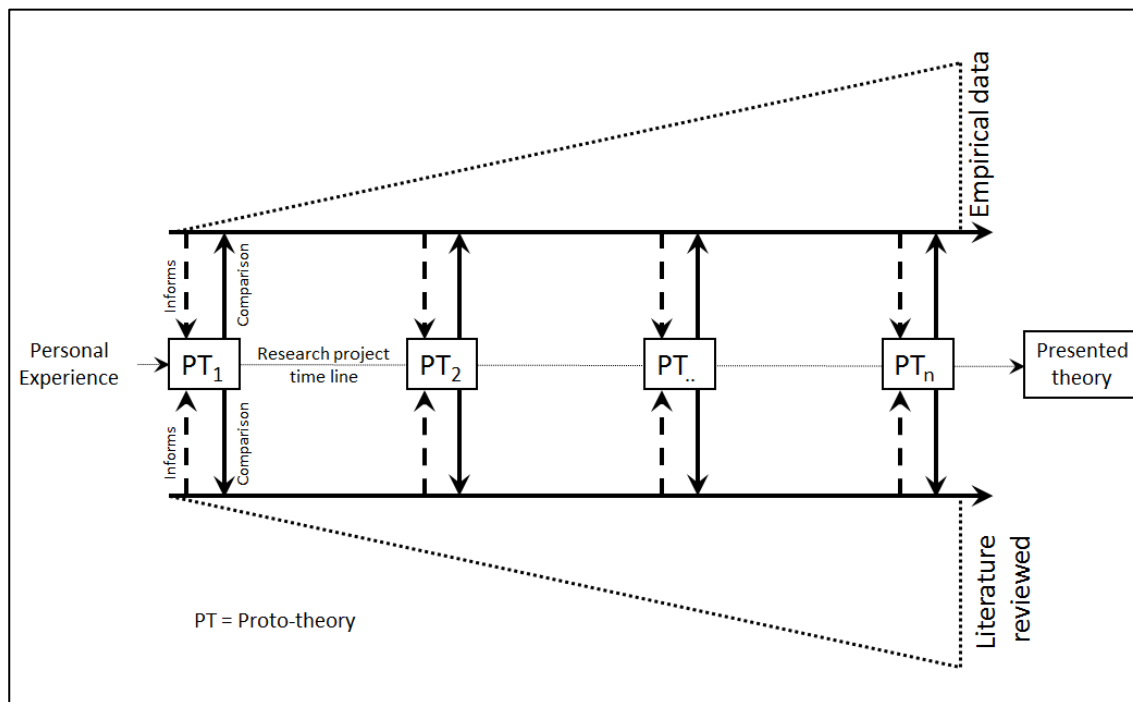


Figure 9 – Diagrammatic representation of the abductive research development process

Such studies entail sustained participation with and observation of projects and groups in context. Data is gathered from documents, conversations, and events, such as lectures, seminars, workshops and conferences. Formal interviews and questionnaires also form part of the data gathering for ethnographic studies (Charmaz 2006). The following sections, summarised in Table 4-1 below, describe the data gathering techniques adopted. The data points referred to are summarised and briefly explored in Chapter 5, and are described more fully in Appendix B.

Table 4-1 – Summary of data gathering undertaken during the research

	Dates	Surveys	Interviews	Observation - Participatory	Observation Non-participatory <sup>2</sup>
Phase 1	09/2013 – 08/2014	Yes	Semi-structured I - VIII	A,B,F,I,J,K	AA - AK
Phase 2	09/2014 – 07/2018	No	Unstructured 1-9	C,D,E,G,H, L-Q	AL – AZ , BA - BE

In addition to these observations and interviews, the researcher engaged with relevant social media communities (audio and visual material review), in particular Twitter and LinkedIn. This served two purposes for the research:

<sup>2</sup> These references relate only to those events with notes included in Appendix B. Other events are summarised in Table 4-2 to Table 4-4 below.

- To identify events and documents that might provide further insight to the research problem; and
- To raise the industry profile of the researcher, increasing the opportunity for engagement with, and observation of, the industry in practice.

The cumulative cases explored at any given point were used as empirical data for the process of proto-theory testing described above. Ethics approval was granted for the project with data stored in encrypted folders on Dropbox, accessed with two-stage password protection.

### **4.3 Sample Definition – Theoretical and Convenience Sampling**

In quantitative studies, it is important to establish that a sample is statistically representative of the population about which knowledge is sought to ensure that the research is capable of generalisation and representative of a wider population. However, in this research, data has been gathered to provide insights for theory formation rather than to make statistically valid generalisations: the aim is to “*generalise theoretically, rather than empirically*” (Yin 1984, cited in Fendt and Sachs, 2008). Therefore, samples need not necessarily be random or representative and can be guided by the need to develop theory. In this circumstance, non-statistical sampling is considered valid (Miles, Huberman and Saldaña, 2014) and has been adopted in this study. Pathological and extreme cases were sought out and explored, along with ‘typical’ projects that provided opportunity for comparative analysis. As the research was industry based, the opportunities for data gathering were influenced by availability. However, while many of the data were gathered through the sponsoring organisation, data gathering was also extended to organisations and individuals outside of the organisation’s boundaries (Section 4.4.2).

## **4.4 Data Gathering: Observations**

### **4.4.1 Participatory Observations**

This research project was funded by and based at Useful Projects and Expedition Engineering, organisations that operate as advisors on construction projects. During the course of the project, the opportunity arose to explore project themes in the context of live projects. Appendix B provides a list of the projects in which the researcher participated during this research project. The selection of projects was guided by the available projects in the office, and as such represents a form of convenience sampling. Such active membership of the researched community means that the researcher can experience many of the same opportunities and barriers to applying innovative practices as other participants, allowing for analytic autoethnography. This increases the opportunity for rich data gathering and hence data and theoretical saturation (Marvasti, 2013).

#### **4.4.2 Non-participatory Observations**

As well as participating in projects, the researcher attended public industry and academic events considered to be related to the research problem. The events were selected on the basis that they may provide further insight to the problem of NMS implementation on projects, a form of theoretical sampling. None of the events were held under Chatham House rules, explicitly so in non-participatory event AZ (Table 4-3). A list of the events attended is included below and in Appendix B. During these events, open-ended field notes were taken to capture insights from speakers, or informal interactions with other attendees. These informal interactions are “ [...] *important not only as means of data collection, but also as means of testing interim interpretations*” (Weick, 1995; Green, Kao and Larsen, 2010). Indeed, early proto-theories were soon found wanting when exposed to the real world in these informal contexts. The field notes were reviewed for memo-writing / proto-theory development during the coding process. These field notes were free-form, and captured in note books that were collated throughout the research project. Findings from relevant documents produced by industrial, political and academic institutions were included in the evidence base and included in the development of proto-theories.

Table 4-2 to Table 4-4 below list the participatory and non-participatory events attended during the research. The participatory events relating to the research total 233 hours, however, the projects themselves lasted somewhat longer. The references in the final column of each table link to the summary descriptions and key findings for each section included in Appendix B. The outcome of the coding process of this data is presented in Section 5.2 below.

### **4.5 Phase 1 : Domain Exploration**

#### **4.5.1 Introduction to Phase 1**

The project was established to explore the lack of NMS implementation on construction projects, yet, it is clear that under certain conditions, such NMS are implemented. The aim of the first phase of this research was to develop a deeper understanding of the contexts under which construction projects implemented NMS (extreme cases), and others where they failed to do so (pathological studies). This exploration was undertaken through a study of the uptake of Cross-Laminated Timber (CLT), a relatively new building material. The study sought to see whether there were any common contexts under which CLT was implemented by respondents for the first time. Two instruments, a survey and semi-structured interviews, were used to gather data. These approaches were adopted to provide the characteristics of both breadth (survey) and depth (interviews). While the results from phase one of this research (Appendix F) are not reproduced in the body of this text, the methods are presented here as the observations provided continued insight throughout the course of the project.



Table 4-2 – Participatory observations undertaken during the research

Duration (research related)	Description	Appendix B Reference
20 hours	Review of Materials databases / Construction materials database tools design requirements elicitation	A
15 hours	Exploration of alternative materials for textile factory in India	B
10 hours	KTN steering committee input	C
20 hours	Opportunities for NMS use on live college project	D
3 hours	Managing energy reduction in a college environment – development of a tool	E
35 hours	Exploring opportunities for glass re-use	F
7 hours	Review of Materials Efficiency Metric for infrastructure project	G
3 hours	Brick v timber assessment of GHG impacts for new building	H
4 hours	Study of open innovation models	I
14 hours	Planning for presentations: <ul style="list-style-type: none"> <li>• Future Cities – context values and appropriate material choice</li> <li>• Delivering small scale, high quality retrofit</li> </ul>	-
2 hours	The Restorative Neighbourhood project workshop	-
35 hours	North Sea oil and gas rig decommissioning and re-use opportunity report	J
7 hours	[Confidential Project]	-
14 hours	Foam Ceramic	K
14 hours	Circular Economy - paper on residual value	L
5 hours	Sustainability opportunity sessions: School project / SIG / Perth	M
3 hours	Orkneys Bio-Economy report (limited)	N
20 hours	Get it Right Initiative	O
1 hour	Sustainability workshop	P
1 hour	Meeting to discuss developing with CLT in South Africa and the UK	Q

Table 4-3 – Non-participatory observation industrial events attended during the research

Event Type	Date	Location	Title	Appendix B Reference
Conference	08/10/2013	London, UK	ASBP – Mainstreaming Sustainable Products: Beyond the Green Guide	AA
Seminar	11/11/2013	London, UK	RAEng – Innovation in Materials	-
Seminar	23/01/2014	London, UK	UCL ISR – Un-burnable Carbon	-
Conversation	21/02/2014	London, UK	Discussion with Sustainability Advisor, Forum for the Future	AB
Lecture	07/04/2014	London, UK	Grantham Institute Annual Lecture – Unilever's Project Sunlight: Sustainable Growth: Paul Polman	AC
Lectures	29/04/2014	London, UK	The Concrete Centre – Innovating with Ferrocement	AD
Seminar	01/05/2014	London, UK	CBRE – Show me the Value! The Value in Sustainable Construction	AE
Seminar	16/06/2014	London, UK	UCL ISR – New Environmentalism and the Circular Economy	-
Presentation	19/11/2014	London, UK	IStructE – Innovation in the WWF Head Office	AF
Seminar	25/11/2014	London, UK	UCL ISR – The UK's Low Carbon Pathway to 2030	AG
Workshop	05/01/2015	London, UK	The Crowd – The CFO's Dilemma	AH
Seminar	28/01/2015	London, UK	ASBP – Embodied GHG as an Allowable Solution	-
Telephone call	26/03/2015	-	USGBC – Regional Credits in LEED	AI
Seminar	08/05/2015	London, UK	Ecobuild – Various talks	AJ
Seminar	07/05/2015	London, UK	The Concrete Centre – Concrete, BREEAM and the Home Quality Mark	AK
Presentation	22/09/2015	London, UK	Sir Robert McAlpine – 'Building a Better Future: Our Journey'	-
Workshop	01/10/2015	London, UK	UKGBC – Embodied GHG : Action and Implementation	AL
Webinar	05/10/2015	London, UK	IEMA – Communicating Value Creation through Natural Capital to the Mainstream	-
Seminar	19/11/2015	London, UK	Supply Chain Sustainability School – Understanding a Client's Need to Build Sustainable Homes	-

Event Type	Date	Location	Title	Appendix B Reference
Presentation	28/01/2016	London, UK	CDSB – Comply or Explain: Review of FTSE 350 GHG reporting in annual reports	AM
Lecture	11/04/2016	London, UK	Grantham Institute Annual Lecture – Christiana Figueres	AN
Seminar	19/04/2016	London, UK	Property Week – Spotlight on Sustainability: How do we Defuse the Eco Time Bomb	-
Seminar	26/04/2016	London, UK	Max Fordham – Sustainable Housing - Beyond the Bonfire	-
Seminar	28/04/2016	London, UK	Sturgis Carbon Profiling – CE in Construction	-
Workshop	2015 / 2016	Berlin, Milan	Ellen MacArthur Foundation Acceleration Workshops	AO
Talk	16/11/2016	London, UK	UCL Lancet Lecture 2016 – Christiana Figueres; Action on climate change for a healthier world – putting the Paris Agreement into practice	AP
Talk	19/11/2016	London, UK	R&D Society event – ‘Not invented here!’ R&D in Construction	AQ
Discussion	21/12/2016	London, UK	Informal conversation about an innovative project	AR
Talk	13/01/2017	London, UK	Cradle to Cradle, the Circular Economy, and the New Language of Carbon	-
Talk	20/01/2017	London, UK	Circular Economy thinking in Construction Conference	AS
Meeting	16/02/2017	Camberley, UK	Observation of Board Meeting: Discussing Innovation in Construction.	AT
Workshop	22/02/2017	London, UK	How will the Circular Economy impact concrete manufacturing businesses?	AU
Seminar	14/03/2017	London, UK	AECOM – How do we Meet the Global Resource Challenge?	-
Workshop	28/03/2017	London, UK	UKGBC – Delivering the Sustainable Development Goals	AV
Conference	04/05/2017	London, UK	GRESB Spring Conference : Leading Sustainability Innovation for Real Estate	AW
Webinar	08/06/2017	-	Carbon Trust – Science Based Targets	-
Webinar	26/09/2017	-	UKGBC – Delivering low carbon infrastructure	AX
Conference	15/11/2017	London, UK	Bloomberg Sustainability conference	AY
Discussion	25/07/2018	London, UK	The Hoffman Centre, ‘Reinventing the Building’, Chatham House	AZ

Table 4-4 – Non-participatory observation academic events attended during the research

Event Type	Date	Location	Title	Appendix B Reference
Seminar	25/03/2014	London, UK	UCL - Behaviour Change and Sustainability	-
Book Launch	06/05/2014	London, UK	UCL - The Behaviour Change Wheel - A Guide to Designing Interventions	-
Conference	04/11/2014	London, UK	UCL Urban Sustainability and Resilience Conference	-
Seminar	15/06/2015	London, UK	UCL Institute of Advanced Studies: Interdisciplinary thinking	-
Conference	09/06/2015	Santander, Spain	WASCON – Resource Efficiency in Construction	-
Conference	08/03/2016	Hamburg, DE	Sustainable Built Environment Conference 2016 – Strategies, Stakeholders, Success Factors	-
Conference	20/04/2016	London, UK	UCL Construction Technology – Road Mapping the Next 5-10 years.	BA
Conference	18/05/2016	Salford, UK	Construction – Building a More Sustainable Future	-
Conference	07/07/2016	Cambridge, UK	Centre for Industrial Sustainability Conference – Capturing Sustainable Value	BB
Talk	15/03/2017	London, UK	Goldsmiths College – Rethinking Capitalism	BC
Conference	18/04/2017	Bath, UK	IASBE 2017 – Creativity and Collaboration (Mixed academic / industrial focus)	-
Conference	23/06/2017	London, UK	Bartlett Doctoral School of Construction and Project Management Conference.	-
Seminar	03/10/2017	London, UK	Prof Roger Levitt (Stanford) Bartlett CPM, Rethinking Infrastructure	BD
Seminar	04/10/2017	London, UK	Prof Roger Levitt (Stanford) Imperial College, Swimming Across Lanes: Addressing Barriers to System-Level Innovation in the Construction Industry	BE

#### **4.5.2 Survey**

The survey sought to provide a wide coverage of specific contextual aspects of CLT implementation to guide the development of semi-structured interviews<sup>3</sup>. The questions were a combination of demographic and attitudinal questions, and questions relating to the experience of using CLT. The survey also allowed for respondents who were time pressed, and potentially uninterested in the subject matter, to contribute to the research with a minimal investment of time. However, using a simple survey could potentially have encouraged respondents to respond without proper reflection. This could lead to respondents conflating reasons for opposing an action. The survey was produced using SurveyMonkey's online survey tool, and after testing was distributed to:

- All architects (n=94) and engineers (n=11) listed on the web sites of the two primary providers of CLT services in the UK as having developed projects in the material.
- All companies on the Construction Index 100 contractors of 2013 (The Construction Index, 2013) (n=100).
- All of the structural engineers on the Building magazine top 100 Engineers list (Building Magazine, 2014) (n=57).
- All architects in the AJ top 100 (Anon, 2013) to the extent that they had not been included in the list of architects using CLT previously (n=92).
- Approximately 15 architects and 15 engineers from each of Leeds and the Farringdon area of London were invited to complete the survey.

Recipients were invited to send the survey to the other members of their project teams. The coverage was intentionally wide in an attempt to gather opinions from as many actors in the industry as possible. A copy of the survey instrument is included in Jones (2014) and not reproduced here. Finally, to gather experiences of CLT use in the wider industry, a link to the survey was made available on the author's Twitter feed (@kell\_engd) and LinkedIn profile. The Building Centre also issued a link to the survey via Twitter to around 14,500 timelines and the Association of Sustainable Building Products promoted the survey on their website.

#### **4.5.3 Semi-Structured Interviews**

In the survey, respondents (n=49) were asked if they would be willing to discuss their responses further. Of those who were willing to do so (n=14), those who had previously used or considered

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<sup>3</sup> These data were gathered at an early stage of the research project development when the implications of the ontological choices were not fully apparent to the researcher. Jones (2014) attempted to analyse the responses in terms of statistical significance to demonstrate causality, without consideration of the wider social context in which projects develop (cf. Dainty, 2008).

using CLT ( $n=12$ ) were contacted to arrange interviews. Respondents who had not used the material had already provided sufficient information to negate the need for more in-depth study. The interviews were used to create studies of CLT implementation, increasing the richness of data available to understand the contexts supportive of implementation and aiding the construction of a model of NMS implementation (proto-theory 6, the 'Material Adoption Model'). A semi-structured interview technique was adopted to allow multiple participants to be asked the same questions, while permitting the researcher to explore commonalities and differences in contexts in the necessary detail (Fusch and Ness, 2015).

Table 4-5 – Summary of phase 1 interviews on CLT implementation

Date / Time	Data point	Participant role
14 <sup>th</sup> July 2014, 11.00am	I	Architect
14 <sup>th</sup> July 2014, 4.00pm	II	Architect
15 <sup>th</sup> July 2014, 10.00am	III	Architect
15 <sup>th</sup> July 2014, 6.00pm	IV	Architect
16 <sup>th</sup> July 2014, 10.20am	V	Architect
21 <sup>st</sup> July 2014, 5.30pm	VI	Innovation manager
22 <sup>nd</sup> July 2014, 3.40pm	VII	Architect
28 <sup>th</sup> July 2014, 2.45pm	VIII	Project manager

From this list, 8 interviews were arranged. Of the remainder, 3 did not respond to the request for interview, and the final respondent was unable to agree a mutually convenient time for interview. This method of selecting respondents for further in-depth studies by theoretical sampling also allowed for the use of information rich, extreme cases that could shed further light on the target concern of CLT implementation. Further, such typical case sampling is considered to be useful in highlighting behaviour drivers when seeking to understand a new area (Patton, 1990). Details of the interviews are reproduced in Table 4-5. The standard questions asked during the interviews were:

- Could you provide some background to the project?
- Why were you chosen to undertake the work?
- How and when did you first hear about CLT?
- Why did you select CLT for the project?
- How did you satisfy yourself, and the client, of technical capability?
- What was the effect on time / costs / embodied energy of using CLT?
- How many times have you used CLT subsequently? Barriers?
- Can you describe other innovative approaches you have adopted?
- Was that approach adopted successfully and were there any barriers?

In addition to these semi-structured interviews, two open interviews were undertaken with engineers (Interviews 1, 2, Table 4-6). These were early interviews undertaken to gain a broader insight into the question of NMS implementation. They were revisited during the second and third rounds of coding of the wider project data during Phase 2 of the project

## 4.6 Phase 2 : Problem Exploration

### 4.6.1 Aims of Phase 2

Having established an understanding of the academic and industrial landscape of construction innovation implementation, the second phase of research sought to develop a model within which the research problem – the non-implementation of NMS – might be described and explored. Having previously established the Material Adoption Model (proto-theory 6) (Jones, 2014), this was to be tested against further bodies of literature and empirical data. If the extant model was unable to accommodate the new data and literature, the model was modified. The process of data sourcing and literature review continued until the point of theoretical saturation.

### 4.6.2 Unstructured Interviews

The second phase interviews were purposively targeted (Patton, 1990) to explore specific contexts in the construction industry. The sample was selected on a convenience basis. The interviewees were project participants who had first-hand experience of projects and who could recount the decision-making processes that led to the implementation or rejection of the NMS. All interviews, aside from Interview 4, which was undertaken using Skype, were undertaken in the participants' offices. Details for Interviews 1-8 are summarised in Table 4-6.

Table 4-6 – Summary of phase 2 purposive interviews

Date / Time	Data point	Participant role
8 <sup>th</sup> November 2013, 9.00am	1	Structural Engineer
17 <sup>th</sup> October 2013, 3.30pm	2	Structural Engineer
11 <sup>th</sup> May, 2015, 1.30pm	3	Client Developer
5 <sup>th</sup> August 2015, 2.00pm	4	Material Specifiers
3 <sup>rd</sup> August 2016, 11.00am	5	Structural Engineers
7 <sup>th</sup> November 2016, 9.30am	6	Sustainability Consultant
5 <sup>th</sup> December 2016, 12.00	7	Materials Manager
21 <sup>st</sup> December 2016, 5.00pm	8	Structural Engineer

A ninth data gathering event, described in Section 4.6.3 below, took the form of a panel debate. Other informal discussions and conversations were held during the course of the research. Key points from these discussions are included in the non-participatory observations section of Appendix B.

Interviews 1-8 were unstructured, open interviews, exploring the experiences of NMS implementation on specific projects. The cases discussed were categorised as either pathological, when an attempted NMS implementation had failed; extreme where the implementation was successful, and comparative if the outcome was yet to be determined, but there was an intention to implement NMS. The categories of cases discussed in each interview is shown in Table 4-7 below. Extreme examples were the main focus for interviews, as they present more ‘surprise’ observations and aid the search for explanation (Peirce, 1998). However, Interviews 1, 2, 8 and 9 also discussed projects on which innovation had been unsuccessfully attempted.

Table 4-7 – Analysis of case outcomes discussed in interview

	Pathological	Extreme	Comparative
Interview reference	1, 2, 4, 8, 9	1, 2, 3, 5, 8, 9	6, 7, 8, 9

The interviews were recorded with the agreement of the participants and subsequently transcribed verbatim by the researcher. No notes were taken during the interviews to enable the researcher to focus on the responses being given by the participants.

#### **4.6.3 Data Point 9 - Focus Group Discussion**

Data point 9 took the form of a panel discussion – a form of focus group – at a conference at Bath University run by the International Association of Bridge Structural Engineers. The panel discussion, entitled “*Why is There so Little Innovation in Construction? A Multi-perspective Debate*”, was proposed and organised by the researcher to act as a data gathering exercise. Focus groups are used by grounded theory practitioners as a tool to elicit multiple rich data perspectives on a given topic, driving research through openness and exploration. Focus groups are a strategy that allows a great deal of data to be obtained quickly (Fusch and Ness, 2015). As with industry workshops, the panel discussion was considered to be a good opportunity to incorporate views of a wider audience, and to validate the findings to date (Green, Kao and Larsen, 2010).

The panel was selected by convenience sampling from contacts of the sponsoring organisations. Panellists were selected and asked to represent the views of various stakeholders in the construction process as shown below. The actual roles of the participants are included for completeness in parentheses:

- Client (heritage structural engineer, material supplier);
- Material supplier (material supplier);
- Architect (architect);
- Structural Engineer (structural engineer / academic);
- Contractor (contractor / project manager).



The panel members were asked to prepare a short presentation on their experiences of innovation in construction, based on the following questions:

- Why does your organisation innovate? What are you seeking to achieve?
- How do you innovate?
- What are the risks of innovating?
- What do you need to successfully innovate?

After the presentations, and a response by the researcher, there was a question and answer session in which conference attendees were invited to debate the points raised with the panel. The session lasted for an hour and was broadcast to a parallel conference in South Africa. Video and sound recordings were made of the event. These were transcribed and added to the pool of data available to the researcher available for coding.

## **4.7 Data Analysis**

### **4.7.1 Surveys**

As has been noted, the surveys provided data at an interim stage of the project (Jones, 2014), guiding the development of semi-structured interview questions in phase 1 of this research. The data provided by these surveys was presented by Jones (2014) and Jones et al. (2016) as potential correlations. However, the sample size meant that the data had limited statistical significance. For the purposes of the critical realist study position adopted here, these data were adopted and used to indicate how common certain events are (Danermark, Ekstrom and Jakobsen, 2002). Accordingly, the frequency, rather than significance or outcomes was considered relevant for the study. The data points were incorporated into the wider study, influencing the development of proto-theories and subsequent interviews.

### **4.7.2 Qualitative Coding and Memo-writing**

Coding was undertaken over three stages in this research. The first iteration of codes were developed during text creation (interviews, field notes, etc.) or on researcher reflection shortly afterwards. This stage allowed for the researcher to reflect on the key themes emerging from the observation. A second iteration of coding was informed by the proto-theories that reflected the pool of data and literature explored to date. This second round of focused coding was undertaken while texts were being transcribed, sometime after the events. This allowed the researcher to view the data anew, and to allow reflexive insight, text comparison, and testing against emergent models. The third and final iteration of coding was theoretical coding, in which the key abstracted concepts developed or adopted during the research were applied to the data. The interviews were also explored through NVivo, the data analysis software tool.

Charmaz (2006) suggests three potential approaches to coding: word-by-word, line-by-line or incident to incident coding. Word-by-word and line-by-line coding force researchers to consider every item of data, with a focus on the meanings, latent, implicit and explicit, of the spoken

words. However, in the context of semi-structured or unstructured interviews, not all of the text will be directly relevant to NMS implementation. These detailed approaches to coding, therefore, were considered to be inappropriate and unnecessarily resource intensive for this research project.

The research seeks to understand the contexts under which NMS are, or are not, implemented on construction projects. In a complex system, this suggests the use of an incident by incident approach to coding that allows for a comparison of project contexts that led to implementation or rejection. Such incident coding aids in discovering patterns and contrasts in research data (Charmaz 2006). Accordingly, in reviewing the texts generated, sections of the data were disregarded as they were considered unrelated to the specification decision itself (Creswell, 2014 describes how not all information in rich descriptions will be usable). After cleaning the data for repetition and clarity, this left a core of data that was appropriate for more detailed coding as described in Section 3.7.2 above.

#### **4.8 Literature as a Source of Secondary Data**

The domain based nature of the problem addressed by this thesis (Winch, 2015) has necessitated an extensive exploration of a broad body of literature relating to the problem of NMS implementation, gathering relevant insights in a “magpie-like” fashion (de Valence and Runeson, 2015). Literature is considered a suitable secondary source of data, forming a basis for theory building (Glaser and Strauss, 1967; Sexton and Barrett, 2005). The key bodies of literature explored are summarised in Chapter 5. These diverse disciplinary perspectives have been used as a means of theoretical triangulation, as touchstones against which to test the emergent proto-theories (Appendix C), and to aid theory building. Figure 56, included in Appendix C presents the areas of study identified for exploration during phase one of the project, in the form of a mind-map. Where possible, literature reviews and meta-studies were identified to provide a broad insight into subject areas.

#### **4.9 Theory Formation**

*“Theorizing means stopping, pondering, and rethinking anew. We stop the flow of studied experience and take it apart. To gain theoretical sensitivity, we look at studied life from multiple vantage points, make comparisons, follow leads, and build on ideas.”*

*Charmaz, 2006*

Theory development began at the very outset of this research, and continued throughout. Memo-writing and diagramming aided the theorising process by enabling conceptual categorisation and abstraction. As proto-theories emerged through this process, two key questions ensured that the research remained focused, and maintained analytic momentum. First, a constant review of the problem space was made with the question: ‘does this theory adequately describe the research problem and evidence?’; second, ‘does this intervention

*necessarily* lead to NMS specification and implementation on a project?’ (after Charmaz, 2006). The first of these questions was answered through the comparison of the emergent theory with the literature reviewed and the empirical observations made relevant to the NMS specification decision. Answering the second question also relied on these tools, but thought experiments (Section 3.8) were also undertaken as a means of reflexivity. Being immersed in the construction industry and projects, both before and during the research project, provided the researcher with sufficient experience to consider the likely outcome of interventions at a project level.

The key emergent proto-theories that were explored during the project are included in Appendix C along with a brief discussion of the influences on the model and the reasons for their being discarded. At key stages of theory development, proto-theories were discussed with both academic and industrial actors. The final framework is presented in Chapters 8 and 9.

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## **5 Review of Data Gathered**

### **5.1 Introduction**

This chapter briefly introduces the data gathered for the research. Following a summary analysis of the interviews and observations gathered during both phases of the study, the chapter discusses the key insights generated from a review of the data. Detailed survey data from the first phase of the study have been presented in detail in Jones (2014) and summarised in Jones et al., (2016, Appendix F) and are not re-presented here.

### **5.2 Summary of Data Gathered During the Research**

Table 5-1 below presents the results of the interview coding process described in Section 4.7.2 while Table 5-2 describes the key issues that emerged during the exploration of the problem through participatory and non-participatory observations. The tables are presented separately as the insights from the distinct modes of data gathering proved to be qualitatively different.

The interviews primarily discussed the conditions under which innovation happened, or did not happen, in construction projects. That is, they set out to explore the endowments of the decision context and decision-makers. Table 5-1 shows the coding undertaken during interview data review (Section 3.7.2.2), beginning with the analysis of the data into codes. In turn, these are grouped into categories, and subsequently into theoretical codes. This outcome of the process of theoretical coding has led, in part, to the discussions in the following chapters.

Data gathered during the participatory and non-participatory events were more focused on developing a broader understanding of the construction industry and its dynamics providing the researcher with insight as to the likely outcome of proposals to implement NMS in given circumstances. Insights from this knowledge acquisition process improved the researcher's ability to undertake the constant comparison and thought experiments necessary for theory development (Section 3.8). Detailed notes from these participatory and non-participatory observations are presented in Appendix B and are summarised in Table 5-2 below. This data was coded independently of the interviews as it represents a separate, albeit related, data set. As a result, Table 5-2 describes the challenges identified in the data to producing a generalisable model of the construction project. Responses to these challenges were incorporated into the development of the research's proto-theories (Appendix C). Table 5-2 provides some illustrative reference data points, before providing theoretical codes that are briefly introduced in this chapter before being incorporated into the discussions in Chapters 6 to 10.

Table 5-1 – Summary of decision context endowments and NMS functions identified during the interview coding exercise

Theoretical Codes		Decision Context Endowments																				NMS Functions																	
		Resources		Decision context						Personal characteristics				Skills, knowledge and experience						Relationships				Certainty		Adoptability		Supply											
		Money capital or process	Time	Selection latitude	Ability to exploit IP / learning	Supportive regulations	Early decisions	Supportive insurers	Site constraints	Supportive procurement	Innovation management processes (client experience)	Supportive Culture (implicit?)	Supportive client / Constraints	Commitment (sacrifice) to NMS implementation	Inquisitiveness / critical thinking	Courage	Broad decision horizons	Creativity (solution generating)	A focus on Personal drivers	Training availability	Experience (reducing Impacts)	Professional judgment	Absorptive capacity	Knowledge management systems	Knowledge awareness & understanding (sub contractors / network)	Trust	Collaboration	Team Communication	Reputation	Ongoing relationships	Evidence of performance (incl precedent)	Warranties	Certainty of performances	Relative Advantages	Comparability / Compatibility	Simplicity	Multiple suppliers / Supply chain	Supply certainty	
Ref.		Y	Y		Y	Y	Y			Y		Y	Y		Y	Y		Y		Y	Y		Y	Y		Y				Y		Y	Y		Y		Y		
1	Structural engineer	Y										Y		Y			Y	Y				Y							Y				Y	Y			Y	Y	
2	Structural engineer	Y										Y		Y			Y	Y				Y							Y				Y				Y	Y	
3	Client - Developer	Y	Y	Y		Y	Y					Y	Y					Y		Y	Y	Y				Y	Y						Y	Y			Y		
4	Material specifiers	Y	Y	Y								Y		Y		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y			
5	Structural engineers	Y	Y	Y			Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y			Y	Y		Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	
6	Sustainability consultant	Y	Y		Y					Y		Y					Y				Y			Y							Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Materials manager	Y	Y	Y					Y	Y		Y				Y	Y	Y				Y								Y		Y	Y						Y
8	Structural engineer		Y	Y					Y			Y	Y	Y	Y		Y	Y			Y	Y		Y		Y	Y		Y		Y		Y	Y	Y	Y			
9	Various	Y	Y		Y					Y	Y	Y	Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	Y	Y			Y	Y		Y	Y	Y	Y	Y	
I	Architect	Y	Y				Y					Y	Y	Y			Y	Y			Y	Y	Y		Y	Y	Y				Y			Y	Y	Y		Y	
II	Architect	Y	Y		Y	Y	Y	Y	Y			Y	Y	Y			Y	Y			Y	Y	Y		Y	Y	Y	Y	Y	Y	Y			Y	Y			Y	
III	Architect	Y	Y	Y		Y	Y					Y		Y		Y	Y	Y		Y	Y	Y		Y	Y	Y		Y			Y			Y	Y				
IV	Architect	Y	Y				Y					Y	Y	Y		Y	Y	Y		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y					
V	Architect	Y	Y				Y					Y	Y	Y		Y	Y	Y				Y		Y		Y		Y						Y					
VI	Innovation manager	Y	Y	Y	Y				Y	Y		Y	Y		Y				Y			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	
VII	Architect	Y	Y									Y		Y		Y	Y							Y	Y	Y	Y				Y		Y	Y	Y				
VIII	Contractor - project manager		Y		Y	Y						Y	Y				Y				Y				Y		Y		Y	Y				Y	Y				
Count		15	16	7	6	5	8	2	3	5	3	1	17	11	11	4	9	14	13	1	7	10	12	4	12	12	7	13	3	8	8	13	4	10	17	10	7	7	5

The codes shaded grey are discussed in this chapter.

Table 5-2 – Summary of challenges identified in the participatory and non-participatory observations

Challenges identified in participatory and non-participatory observations	Data points	Theoretical coding
1. The decision to specify an NMS can impact costs and time budgets negatively; Data gathering, knowledge management and skills development are challenges for undercapitalised companies.	A, C, E, H, K, O, P, Q, AA, AD, AJ, AS, AT	(i) Accommodating the elaborating impacts of NMS specification
2. Simpler comparable technologies are easier to implement as they don't require changes in behaviour.	AG	
3. Need for much more communication and collaboration when innovating.	AD, AS	
4. Projects are not static entities, they change over time.	C, N	
5. Timing is key: how does the timing of a specification decision influence the decision outcome?	D, E, M	(ii) Emergence – the shaping of the conditioning structure
6. Data needs change as the project proceeds, from the general to the specific.	A, C	
7. Budgets drive decision-making, setting budgets first limits outcomes.	B, D	
8. Early decisions limit later ones.	D, AK, AR	
9. Timing of intervention influences uptake.	P, AK, AL, AR	
10. Timing of appointment affects ability to influence NMS specification.	P	
11. How does NMS implementation happen when budgets (time and cost) drive behaviour, and there is a need to demonstrate a business case and quick return on investment for their implementation?	E, F, J, L, M, Q, AA, AE, AH, AJ, AQ, AS, AT, AU, AV, AW, AX, AY,	(iii) NMS performance
12. The NMS needs to perform at least as well as the dominant solution (mostly).	B, F, J, AZ	
13. Uncertainty over what constitutes 'good' performance in NMS attributes.	G, AL	

Table 5-2 (continued). – Summary of challenges identified in the participatory and non-participatory observations

Challenges identified in participatory and non-participatory observations	Data points	Theoretical coding
14. Can performance criteria be ranked? How are performances distinguished?	B, AE	
15. Tightly defined scopes of work or analysis limit consideration of NMS.	M, N, AM, AS, AT	
16. There is a need for some form of external stimulus to provoke change in specifying behaviour; Research must consider both demand for and supply of solutions.	N, AA, AE, AI, AO, AP, AQ, AS	(iv) Decision-making; the exercise of agency
17. Decision-makers are primarily influenced by the opportunity to create a competitive advantage, but some things are too important to be left to competition.	O, AB, AQ	
18. Aligning conceptions of value can influence decision-making.	D, AC, AE, AH	
19. Different actors have different levels of knowledge and experience. Organisations have different attitudes to knowledge search and creation.	B, H, I, Q	
20. The problems of sustainability in construction are multifaceted, and perceived differently by individuals and organisations, influencing the choice of 'best' material for a job.	A, D, G, P, AD, AE, AI, AS	
21. Important to consider the specific supplier of materials as they each has differing recipes, manufacturing processes.	AA	(v) Contingent nature of the decision's conditioning structure
22. Interventions must reflect the value drivers of the client, stakeholders and key decision makers, influencing these is challenging.	D, E, F, H, M, AE, AL, AM, AO, AP, AR	
23. Cost is not always the problem, it can be inconvenience (or time).	J	
24. The industry is fragmented, and the project is delivered by nested supply chains with conflicting interests in which decisions are made and validated at various levels.	D, AQ, AT, AX	
25. The choice of project / PBO leader influences the outcome of implementation proposals.	M, AC	
26. The choice of procurement route influences whether or not interesting choices can be made.	P	



## 5.3 Data Analysis

### 5.3.1 Introduction to the Data Analysis

Sections 5.3.2 to 5.3.7 describe the data included in Table 5-1, grouped by categories. Descriptions are supported by verbatim quotations and references to supporting participatory or non-participatory events, as appropriate. Section 5.3.8 then explores the outcome of the analysis of the observation events before Section 5.4 discusses some specific themes emerging from the data gathered.

### 5.3.2 Resources

The need for physical resources was discussed by every interviewee. The physical resources most frequently identified as being supportive of innovation implementation were those of time and money. This was unsurprising given the commercial and time pressured nature of the construction project context. However, in addition to being identified as necessary resources, they were also seen to both constrain and promote NMS specification. Some examples from interviews are below:

*"[cost] takes an unnecessary precedence over everything that we do."*

*Data point 9*

*"It saved us time because we didn't have to change all the sizes later."*

*Interview IV*

*"... the only thing that we're assessed on are the cost savings."*

*Interview 2*

*"... If it's costing more, maybe it's not the right thing..."*

*Interview 7*

*"...we're tying our designers down to a tiny fee usually, an inadequate programme usually, but we're asking them to do more work to deliver innovative designs, innovative ideas for the benefit of somebody else."*

*Data point 9*

*"The developer... he's looking at his margin really."*

*Interview 1*

*"... I'm more worried about time because people may not have the time to make the right decisions, or to step back and say 'would it be interesting to do this, or not do this' ..."*

*Interview 7*

This suggests a variable nature of the resources of time and cost in the construction project as both decision constraint, limiting the project opportunity to implement NMS, and object of improvement, presenting a motivation to implement NMS. Further, these two resources were considered to both be necessary enablers of innovation, providing project actors, in part, with the necessary capability to implement NMS.

These key resources were the subject of discussion in almost all of the interviews and raised at many of the observation events, but no clear distinction was made between the differing roles that they play in NMS implementation. Distinguishing these functions may help with analysis. It was interesting to note that costs were not explicitly discussed by the construction project manager (Interview VIII). This interview primarily discussed the challenges of NMS implementation – the project manager's cost and time boundaries having already been established for him, limiting his solution space and constraining the decisions that he might make.

### **5.3.3 Decision Context – Endowments Supporting NMS Implementation**

#### *The Importance of a Supportive Client*

The interviews highlighted the importance of the context in which the specification decision takes place. The context driver described most frequently in interviews as supporting implementation was that of a supportive client. This reflects the client role in both defining the project's scope, and funding the project. Surprisingly, there were no specific discussions relating to client size or type, interviews focused more on the client's conceptions of value as creating the opportunity to implement NMS (cf. Section 5.3.8):

*“...it's all about identifying and mobilising value...”*

*“...we look to maximise the value or the quality of each square metre.”*

*Interview 3*

*“So you need to [...] show that there is value in doing what you're doing.”*

*Interview 7*

*“Quality has a value to clients, it may not necessarily have to other parties, so some of the intangibles are hard to value” “...whether that has value to clients and contractors is, you know, depends on who you ask...”*

*Interview 1*

These value judgments were seen to vary by person to person and project to project, highlighting again the contingent nature of the opportunity to implement NMS on projects. At non-participatory observation event BC, one of the speakers described how these value judgments could be market focused, non-market focused, or some mixture of the two. Any number of factors can influence what a decision-maker feels is important to their decision.

One theme that did link several of the contexts in which NMS were implemented was the source of project funding. Six of the interviews described NMS implementation on projects that were privately funded, nine were funded by public bodies, typically schools. The remaining two, a notably small proportion, were focused on projects funded by financial institutions. These financial institutions are influential project stakeholders, placing demands on the financial returns expected from a project on which the NMS is implemented, restricting the opportunity to implement potentially more expensive NMS, leading to a prioritisation of certainty of outcome over inventiveness.

As well as the key influence of the client, early decision-making was also described as influencing NMS implementation. In particular, this was evident in the interviews exploring the implementation of CLT, in which the proposal to implement was made early, and was typically made central to the project's concept. For example,

*"The sketch says CLT [...] that remains your highest context factor in any discussion or argument, [...] you just come back to that. If someone says to you 'what colour do you want the walls to be?' you think 'what's this going to do to the CLT?'"*

*Interview II*

While this did not stop other project actors from subsequently attempting to remove this novel product from the project, it ensured that those attempts failed.

The criticality of the specification decision timing was made evident in participatory observation D where proposals to implement NMS on a university project were resisted at RIBA stage 3, as too much effort had been committed to delivering the typical solution to the problem at hand. This highlights the need for a contingent framework in which to explore the specification decision's conditioning structure.

There are four other matters that were discussed relating to project contexts that deserve attention, and they are discussed in turn here.

#### *Selection Latitude*

Where the decision context is specific as to the material solution to be adopted in the construction project, the specifier's solution space is severely restricted, precluding all other options. This can either ensure the use of NMS, or preclude it. Where decision-makers are given latitude to specify materials, for example, based on their performance, they are presented with the opportunity to implement an NMS that addresses their own conceptions of value.

One interviewee highlighted a downside of this latitude for those hoping to implement NMS on projects ("*... or equal approved, that's where the problem lies.*" Interview 1). Contractors do not typically welcome restrictive specifications, as it limits their capacity to improve their margins on projects. As such, specifiers will often be expected to caveat their specifications for materials, including NMS, with the phrase 'or equal approved'. This provides contractors, and their sub-contractors the latitude to alter the specification to reflect their notions of value over those of the initial material specifier. However, in the researcher's experience, such approval is not always sought.

#### *Supportive Regulatory Framework*

Similarly, regulations can require that buildings or materials demonstrate a particular performance, or they can specify particular materials. In the UK, performance-based regulations are typical. However, it was also considered important that regulations keep up with

emergent technologies. Interviewees (e.g. interviews I, III) described how CLT was being assessed by regulators using rules for traditional timber frame building systems. This presented the teams with challenges as the CLT fire risk was substantially lower than for traditional timber frame structures. Regulations were also seen as being key drivers for encouraging the use of NMS on projects in several of the observation events, for example, data points AE, AL and AM.

#### *Ability to Exploit Intellectual Property / Learning*

The costs of learning about or developing NMS must, for the investing company, be associated with some form of return on their investment. Typically, this return is reflected in their ability to win new work due to their having a competitive advantage over others bidding for the same work:

*“...the next time round, they would [...] know what to expect and sharpen their pencil. And we would end up with a cheaper, better, more competitive rate ...”*

*Interview VI*

However, value might also be derived from opportunities to provide a company's services to a new, or niche market, or preparing them for a change in regulations (Appendix A). Where there is no value to be derived from the investment beyond the current project, project actors would expect the project at hand to cover the costs of development or learning. This has been observed on longer term projects, such as water infrastructure projects<sup>4</sup>. Anglian have incentivised their supply chain to develop new, low embodied GHG solutions by the use of long-term back-to-back contracts reflecting Anglian's business plan (Blair, 2016). The availability of long-term contracts to provide the solutions developed enable the exploitation of the intellectual property developed through supplier investment in pursuit of Anglian's objectives (data point AT).

#### *Supportive Procurement*

The choice of procurement route in construction projects also influences the context in which decisions are made (Interview 5). The procurement route, in essence, describes who has decision-making authority and the latitude within which they make their decisions. For example, under Design and Build contracts, contractors are typically provided with performance specifications that they must meet, and are left with much latitude in how they do so. Conversely, traditional forms of procurement place much of the decision-making authority in the hands of the architect, as client representative. The procurement route influences how decisions are parcelled out to PBOs, and how they are bound. It is beyond the scope of this

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<sup>4</sup> Water industry regulations (AMP6) require that water suppliers consider the total costs of their asset management programmes, both operating and capital costs. This has created an increased attention on capital costs. Infrastructure focused actors have determined a link between reducing embodied GHG and capital costs in infrastructure projects, and are therefore incentivised to reduce embodied GHG.

thesis to explore these procurement routes and ensuing project structures individually. However, it is clear that a framework in which to locate and assess specification decisions' conditioning structure and elaborating impacts must be able to accommodate a variety of procurement routes.

One aspect of the decision context that was mentioned by only one interviewee was the need for an organisation culture that was supportive of innovation. This was unexpected as the literature indicates otherwise (e.g. Kissi et al., 2009). On further reflection, however, it was considered this might be related to the fact that interviewees were already involved in the use of new technologies, and so the culture in which they operate is not necessarily considered to be unusual or worthy of comment. The influences of organisation culture on innovation implementation are discussed further in Section 9.5.3.4.

#### **5.3.4 Personal Endowments Supportive of NMS Implementation**

*"Innovation takes time, it takes money, it takes people, it takes commitment and collaboration, creativity"*

*Data point 9*

The next group of endowments discussed in the interviews were the characteristics required of those engaged with NMS implementation on construction projects. These characteristics were well represented across interviews, and are discussed below. Again, it is clear that the presence, or otherwise, of these characteristics is contingent on the project at hand and the individuals engaged on the project.

##### *Creativity / Inquisitiveness*

The creativity and inquisitiveness of those promoting NMS was discussed by almost all interviewees. As many of the interviewees were designers, this might be expected. This creativity encourages the exploration of new areas in search of new knowledge and solutions (e.g. data point B). However, some project participants would go further than others:

*"...all the engineers in the team weren't starting by thinking about what the code or design guidance would let them do. Everyone was looking at really trying to look at the depth of the problem and working with the rest of the team. [...] as a contrast to that, [...] we're working with a small [component] fabricator [...] and [while] their in-house engineers seem very capable [they] approach it from the point of view that 'that's the intent, and what does the code let me do? How do I follow through the steps of the code to show that?' Which is a different way round – if you approach it from that point of view, it's much harder to have any innovations that create value."*

*Interview 5*

This sense of enquiry, the 'intellectual challenge' (Interview 2) of taking a "step back and say[ing] 'ooh would it be interesting to do this, or not to do this'" (Interview 7) drives some

people, but not others. While it would make for an interesting topic of exploration, this thesis limits itself to acknowledging that different project actors perceive the world differently. Some will be willing to push boundaries and explore new areas, others will not. The challenge lies with accommodating those varying perspectives into a framework allowing for the selection of case-appropriate interventions to promote NMS implementation on projects.

#### *A Focus on Personal Drivers*

Inquisitiveness and creativity represent forms of personal value generation:

*“If you care about some other things, which might be the thrill of seeing something new, or it might be because you believe that we need to change our construction culture to become more sustainable, more communal, or more local, or you have some kind of mission or agenda, then you have to compromise on some of those [profitability] aspects...”*

*Interview 1*

However, this covers a vast number of things that an individual might care about. It is clear that these personal value drivers influence an individual's decision making. Indeed, a concern to reduce embodied impacts of construction materials led to the development of the research project. It is important that this research capture these personal drivers of value, and describe how they interact with the drivers of value of other project stakeholders.

#### *A Commitment to Implementation*

*“...we went through an unbelievably intense probably 8 weeks [...] to put it in ...”*

*Interview 8*

*“... you'd often still be there [late into the night], talking through, sketching it and exploring it and seeing why it doesn't work – pushing and seeing what was interesting to people ...”*

*Interview 5*

A willingness to commit to a detailed exploration of an uncertain solution is seen as necessary to NMS implementation on projects. This exploration is typically expected to take more time than designing a typical solution to a design problem to code. On time constrained projects this might require the sacrifice of personal time, as demonstrated by the quote above, or at a project level, a willingness by the project actors to invest in learning and committing to NMS (“Normally, we would just absorb [the cost], as a practice”, Interview 8). Such a commitment requires that the team be motivated by the need to implement the NMS, through their own personal or organisational value drivers.

#### *Broad Decision Horizons*

Typically, work packages are delegated to design practices with very tightly defined boundaries:

*“Most lawyers are quite exceptional at putting the contracts together, they narrowly compress the [project manager] as they do the engineer and everyone else down to a very narrow band of services...”*

*Data point 9*

Remaining within this scope of works ensures that projects deliver to time and budget as anticipated, responsibilities and liabilities are understood, and that participating project actors can make a return on their efforts. However, many interviewees also highlighted the need for decision-makers to consider factors beyond their own narrow scopes of work if new technologies were to be implemented onto projects. Three interdependent decision horizons have been observed during the course of this research.

- **Time.** How far into the future, or past, a decision-maker looks to inform their decision. This horizon can have a strong influence on decisions to implement low embodied GHG materials on construction projects as concerns over the future will be considered as well as the current day concerns of profitability. Data point M highlighted the short-term perspectives typically adopted on construction projects, while data point AC showed the influence of longer decision horizons on sustainable behaviours.
- **Scope.** The factors beyond their own professional requirements that a decision-maker takes into account when making their decisions. That is, to what extent do they consider the elaborating impacts of their decisions on other professionals' work?

*“When he’s designing he’s not just thinking ‘structure, structure, structure’, It has to be aesthetically nice.”*

*Interview 8*

Data point M highlighted the contingent nature of this decision horizon, describing how proposal implementation was dependent upon the perspectives of the project leader.

- **Knowledge.** This describes how far a project actor is willing to explore the limits of their own professional domain, for example, going beyond the building codes as described above.

### **5.3.5 Skills Knowledge and Experience**

While the previous section described the personal characteristics of the individuals that are supportive of NMS specification, this section considers the skills knowledge and experience that individuals may have, or have access to that encourage NMS implementation. That is, the individual's endowments at the point of specification.

*Knowledge, Awareness, Understanding / Absorptive Capacity / Available Skills and Knowledge*

These focused codes are considered together as they each reflect aspects of the influence of a decision-maker's prior experience on the specification decision.

When considering incorporating new solutions onto projects, there will be a degree of uncertainty caused by unfamiliarity (*“Uncertainty is not seen as being a good thing”* Interview 4).

The extent of that uncertainty will be a function of the decision-maker's prior knowledge and experience of use in the material. If a proposal is made to use concrete as a structural material, for example, a structural engineer, typically well versed in concrete structures is likely to feel relatively certain about how to address the design problem at hand. However, when faced with a need to use an NMS for the first time, the engineer is likely to have a degree of uncertainty as to how to tackle the challenge.

*"... It's human nature, if you've done something before, you know what you're going to expect. And therefore you're more comfortable with it. If I said to you how long does it take you to walk from the train station to your college, you'll say 'I can do it in seven minutes [...] I do it every day'. You'll be fine with that. If I told you 'right you're going to go to Manchester next week and [...] go to this hotel, how long is it going to take you to walk there? You'd umm and ahh, and you'd probably guess but you'd cover yourself [for the uncertainty]."*

*Interview VI*

This uncertainty leads to perceptions of risk that were considered to have a detrimental effect on CLT implementation:

*"There was a skill deficiency in terms of carpentry and joinery to a degree, and there was a perception of fear and risk and cost associated with the unknown."*

*Interview 1*

*"Risk always get in the way..."*

*Interview 3*

However, where individuals have kept themselves abreast of technological developments, or have experience in the use of a technology, they are likely to have a base level of awareness and understanding of the solutions, reducing their uncertainty and perceptions of risk, and increasing confidence.

For those who do not have prior knowledge and experience with a technology, two main ways of dealing with this uncertainty were observed in practice. The first was the search for and development of new knowledge by the impacted project actors (e.g. Interviews 2, 5, 8 and II, data point A). This openness to new knowledge is a function of their absorptive capacity (after Cohen and Levinthal, 1990) and can be reflected in an individual's or organisation's willingness to engage with sources of new knowledge, such as universities, journals or trade events. Those organisations or individuals with low absorptive capacity may struggle to identify or explore new solutions. However, organisations' willingness to engage in this knowledge development process varied across projects. The second way of dealing with uncertainty was through the 'passing on' of that uncertainty to a specialist in the technology or discipline. For example, each of the CLT projects discussed during phase one of the research involved the sub-contracting of the detailed design on the CLT frame to a specialist provider, someone for whom there is significantly less uncertainty because they understand the technology.



*"Our supply chain knows how to deliver it for us."*

*Interview 1*

In a similar manner, clients will employ architects, structural engineers, quantity surveyors etc., when they do not have that experience in-house.

#### *Professional Judgment*

One other notable aspect of skills and knowledge observed related to the exercise of professional judgment, discussed in 10 of the interviews. A willingness to apply professional judgment demonstrates a designer's self-confidence in their ability and a willingness to embrace a degree of uncertainty. This confidence was discussed at some length in Interview 8:

*"So it was very stressful and .. again there's lots of things that come into it, but that's part of the nature of [it] if you want innovation, I think it's the [all] out nature of some of these things that when we make decisions, it's not 100% certain".*

*"This is what makes this place so good to work [at].. because you sit there and go 'yep, it's a good idea. We have to make it work, because it's a good idea'. It's like, why would you not? It's a pain in the [neck]. [...] I think there's a general confidence with experience which means you can go 'yeah I think we'll be able to get this to work'."*

*"We knew it was going to work. It's that gut feeling."*

*Interview 8*

A willingness to accept uncertainty is particularly important in the early stages of a project due to the uncertain nature of many of the design decisions. By proceeding on the assumption of the use of known solutions to a design problem, much of this uncertainty can be removed. However, where the context requires the use of a new technology, this uncertainty may be unavoidable. In such circumstances, the ability to make confident and early judgments on the suitability of a solution will allow design to advance and give the design team and client confidence.

### **5.3.6 Relationships**

#### *Collaboration*

The next coding group in Table 5-1 relates to relationships, highlighting the need for collaboration on projects. In a fragmented industry with specialist knowledge residing in distinct organisations, the ability and willingness to work together to address problems new to project actors is considered important (cf. data point AU). This collaboration involves the, often intensive, exploration and co-creation of solutions through an exchange of views, knowledge and experience.

*"It's also about the time that people would spend together on some of those things. Because it's about the dialogue that would happen ..."*

*Interview 5*

*“It was the way the team interacted with each other. [...] interesting ideas came out of it. I think in particular, it was about the way [Engineer] and [Architect] interacted with each other. Which led to a lot of interesting ideas – an openness to ideas being put forward and to being explored, and a willingness to put forward ideas which might not be right.”*

*Interview 5*

*“Communication is another enabler for innovation, they are saying that good communication promotes better collaboration and the transfer of ideas and proposals.”*

*Data point 9*

Where solutions are developed collectively, the decision criteria of each participant can be explored and integrated into a final design option. Solutions that are created without this collaboration, considering the needs of only one party, can cause unanticipated impacts on other project participants, and a refusal to accept a design proposal. While collaboration, and by extension communication, is necessary on all projects to some degree because of the need for project coordination, this need is enhanced when implementing technologies that are new to all participants to ensure that need for, and knowledge of, the new technology is shared.

*Ongoing Relationships, Reputation and Trust*

The role of relationships, reputation and trust were described by a number of interviewees as being important to the implementation of new technologies on projects. In particular, trust was discussed in several different contexts. As well as the trust developed between members of the project team to do their jobs to ensure delivery, there was also the implicit trust that the client placed in their advisors to use their best endeavours on a project. These ongoing relationships between individuals and organisations were described as being useful to ensure that teams knew what to expect of each other in terms of performance and commitment to the project. Where organisations' interests aligned, this could lead to repeat work.

*“Because of our relationship with [architect] on previous projects [they knew that] we do a lot more than say ‘you can have this structure’.”*

*Interview 4*

For example, one senior engineer described how trust supported their pursuit of innovation. The engineer had identified an innovative design solution to a problem. They were confident, given their experience and knowledge, that the solution would be effective. The rest of the design team, having worked with the practice before, accepted that the proposal should be explored further, despite it being highly unusual. This demonstrates a form of relational trust (Kadefors, 2004) or confidence in the engineers' ability on the part of the design team as well as a willingness on the part of the client to allow the team to deliver a solution that meets their requirements without being overly prescriptive (Section 5.3.1, data point AX). Where the PBO

in question is trusted, the threshold for rejecting an NMS implementation proposal may be raised, with reliance being placed on the advisor's word that they have confidence in their ability to deliver the solution. Where such relationships haven't been established, an organisation's reputation or prior work might be used as a surrogate by which to judge them. Similarly, the existence of a relational network influences the ease of access to new knowledge (data points K, AD). For example, at data point AD, a speaker described how they knew, and could pick up the phone to, a specialist in a particular material solution, reducing the time taken to access the relevant data.

### **5.3.7 Endowments of the NMS**

Trust was also used often in connection with the material solutions on the project (e.g. *"once the contractors trust it, then you're in."* Interview IV). This highlights the importance of confidence in both the team, and the materials that they are working with. In addition to the advantages discussed in Section 5.3.8, the following characteristics of technologies were described as being important to implementation.

#### *Certainty and Evidence of Performance*

The majority of interviewees discussed either the importance of certainty of performance or evidence of NMS performance as being important for successful implementation on projects. This evidence can be provided through information provision or the search for precedents (cf. data point J). This is a reflection of a need for longevity to ensure that buildings will perform as expected over their anticipated life. Data point 9 supported this perspective:

*"...they like to know that their building is going to last."*

*Data point 9*

Uncertainty over building performance is not conducive to NMS implementation (Section 5.3.5). Therefore, the data suggests that proposed solutions must deliver, and be able to evidence that they can deliver, the performances expected of them. Those specifying NMS will be held accountable for any failures in the material or product, and may face considerable loss as a result of under-delivering performance (data point AJ). The implications of failure can also be catastrophic.

Addressing this lack of certainty by the creation of an evidence base requires an investment of time and money. While some PBOs are willing to undertake this investment to ensure delivery, others may not be. Further, time-bound projects may not have time to confirm these performances, even in the face of accelerated testing.

*"You can't prove anything as 120 year design life."*

*Interview 7*

*"I'm not a firm believer in radical new materials, because history has taught us that you only know that something is going to last 50 years when it's been there 50 years"*

*Data point 9*

### *NMS Adoptability*

The data in Table 5-1 highlights the importance of two of Rogers' (1995) features the influence the adoptability of new technologies: simplicity and comparability. In the interviews, simplicity was discussed frequently.

*"Many clients and contractors of ours recognise that interfacing with timber with wood screws is actually quite simple. Timber is a very forgiving material."*

*Interview 1*

*"We thought it could be made, relatively simple. Not super-simple, but relatively ... and it could be quite simply communicated."*

*Interview 5*

This simplicity of a product and communication about it enables a rapid understanding of new technologies. This understanding, in turn, leads to a reduction in their perceptions of uncertainty, and hence risk. Similarly, the comparability of products is considered to reduce the expectation of additional costs, through re-tooling, or re-training, requiring little change in behaviour at the point of use (data point AG).

### *Certainty of Supply*

The final coding group relates to the supply of NMS. Two factors were considered important by the majority of interviewees. The first was the ability to get bids from multiple suppliers. For example:

*"I went to the procurement manager and I asked him to place an order with this company. He told me he needed three quotes. I explained to him that this was innovation, and that there aren't three companies that do this particular type of thing that we'd spent three or four months talking to the supplier about [...]. I could not get this past the procurement manager because I couldn't give him three quotes. Because he had a piece of paper as part of his job description that said that he needed to get three quotes for everything."*

*Data point 9*

*"We had to be able to tender it. You can't come up with something which only one person can deliver, one contractor can deliver."*

*Interview 5*

Requiring multiple suppliers to tender for work is a common approach to procurement in construction and elsewhere in industry, with purchasing organisations being keen to ensure that they are not exposed to a monopoly supplier who may take advantage of their position (data

point P). Further, those charged with the delivery of the construction project, will want to ensure that delivery is not held up by an intermittent supply of their construction materials. If this cannot be guaranteed, they may be exposed to penalties for the delay (data points AQ, AS).

### **5.3.8 Coding of Observation Events: Peering Through the Morphogenetic Lens**

A review of the observation events led to the development of five theoretical codes that broadly reflected the morphogenetic perspective adopted in the research. Section 2.2.5 describes how the morphogenetic lens encourages researchers to adopt an evolutionary perspective of the problem of structure and agency. This perspective requires an understanding of a decision's conditioning structure, the exercise of agency itself, and the elaborating impacts of the decision on the conditioning structure of subsequent decisions. The codes revealed mirror these requirements.

#### *Analysing the Conditioning Structure*

In static situations, for example on a manufacturing production line, the making of decisions can be a relatively straightforward exercise. Actors exercise their (limited) agency within well-defined parameters. The conditioning structure of their decision-making is known and stable, and their solution spaces are tightly defined. However, a review of the data suggests that this contextual stability is not a common characteristic of the construction project. In construction, the conditioning structure of performance objectives and endowments (Section 2.2.5.2) emerge throughout the evolutionary project development process (theoretical code ii), meaning that at the point of decision there is uncertainty as to the ultimate shape of the solution space. Further, a specification's conditioning structure is contingent on the project actors selected to deliver the project, their location in the supply chain, their performance objectives, and their willingness to commit endowments to the project (theoretical code v).

#### *The Opportunity to Exercise Agency in Pursuit of Value*

Under theoretical code iv, relating to the act of decision-making in the construction project, key themes emerged from the data that provide insight supporting the analysis of the contingent conditioning structure. In particular, decision-makers' conceptions of value driving their decision-making were evident in many of the observations and represent something of an organising principle for the data. That is, decision-makers' notions of value influence their performance objectives for the construction project, influenced by the organisations in and projects on which they make those decisions.

*"The builder mentality is 'I want you to pay me to do it again, the way that I know will work, and I know that I will make a profit on, and I can just go home'."*

*Interview 1*

While these value drivers typically related to a business case, ensuring cost parity, or securing competitive advantage, they were very important in influencing behaviour. The pursuit of individuals' or PBOs' value drivers were tempered by the multi-party nature of the project, and

the conflicting performance criteria on the project. This led to conflicting value drivers. To ensure NMS implementation these competing interests must be aligned, or placed in some form of preference order. The question then turns to what these drivers of value might be, how they can be aligned, overcome, or ordered when making decisions.

#### *Elaborating Impacts of the Exercise of Agency*

*“A lack of time, skills and funds retards change.”*

*Data point AT*

*“Organisations and projects need to have resources to be able to innovate.”*

*Data point 9*

Theoretical coding of the participatory and non-participatory observations highlighted how for successful NMS implementation projects must be able to accommodate the elaborating impacts of implementation (theoretical code i). Most typically, the elaborating impacts mentioned related to project time and cost. This is consistent with the interviews that discussed the need for money and time to absorb the elaborating impacts of the specification decision. However, others discussed the impacts on other building and project performance attributes, such as health and safety, working conditions, or the final building aesthetic. However, there was no structured discussion of what these elaborating impacts were, or why and where they arose.

Complex or novel NMS can be expected to lead to large elaborating impacts, while simple well understood interventions lead to limited impacts (Interview 5).

#### *NMS Performance*

As with the interviews, there was a significant amount of discussion surrounding the contingent performances of NMS (theoretical code iii). As these discussions typically centred on time and cost disadvantages, the fact of NMS implementation, observed during phase one of the study, could be considered to be a surprise, given the anticipated elaborating impacts of novel technologies. However, irrespective of the performance in question, discussions often described how NMS must perform at least as well as the dominant solutions to be considered for implementation.

## **5.4 Emergent Themes**

### **5.4.1 Contingency and Emergence**

Section 5.3.8 described how the conditioning structure of the specification decision evolves over the course of the project. Indeed, the decision's conditioning structure is dependent upon on the timing of the specification decision, the project actors already in place, the decisions that have already been made, and the sanction for breaching these decisions (*“if you do something new, you might get fired”*, data point AQ).

If project actors are to assess the suitability of interventions to promote the implementation of NMS onto construction projects, there needs to be some means of locating and describing the decision's conditioning structure at the point of specification.

#### **5.4.2 Consideration of Both Supply and Demand**

*"You must consider both the supply and demand side solutions"*

*Data point BC*

Every interviewee made reference to the need for an NMS to be able to deliver benefits to the project. This advantage was most frequently, but not always, described in terms of the influence of implementation on project programme or delivery budgets. For example, it was seen as a motivator to implement NMS:

*"A lot of innovation delivers a lot of benefits, but time and cost are just the most highly prioritised and most easily quantified. I think that one of the challenges is that lots of the innovation [...], has lots of intangible or difficult to quantify benefits and that makes it more difficult to justify."*

The expectation of the interviews was that their focus would be on the project contexts and endowments that are supportive of NMS implementation. While these endowments were indeed discussed, there was also a significant amount of discussion about the characteristics of the NMS under consideration. In particular, it was considered critical that the implementation of an NMS addresses some unsatisfied project need that wasn't being addressed by the existing options. For example:

*"The product or the innovation that you're putting forward has to be answering something – a question that they've asked. It has to be answering their aspirations and their values in some way ..."*

*"You can't sell cleverness, you can only sell benefits."*

*Data point 9*

Indeed, interviewees unanimously described both the availability (supply) of some form of relative advantage by the NMS over the dominant solutions, and a client's support (demand) as being important to successful NMS implementation. This client support is interpreted as a reflection of their conceptions of value. This interplay between demand and supply is incorporated into proto-theories 4 onwards.

The observations also highlighted the importance of considering both the demand for (theoretical code v) and the supply of NMS (theoretical code iii). This calls for an exploration of the factors shaping the specifier's solution space for the specification decision, and the location of the NMS in relation to that solution space. Indeed, were the research to consider only one of these aspects, the research might be considered incomplete.

### **5.4.3 Approaches to Addressing Project Performance Needs**

While not specifically discussed in any individual interview or observation, five distinct approaches to addressing performance needs were observed during the study (in particular, data points B, F, AK and Interview 5). These are described below, and will be discussed further in the thesis.

- Search for a suitable product on the market to address the performance gap (data points A, B). Here, performance information is obtained from the material suppliers. This process can be undertaken rapidly, with a specifier using their existing network and knowledge. It can also be an iterative process, with specifiers testing multiple potential solutions against the performance objectives established for the project. Solutions that do not provide evidence relating to new performance requirements or expectations, that is, beyond those typically requested, may be discarded in the anticipation of additional time and cost expenditure on search. This approach to search and selection is common and described in the literature (e.g. Mackinder, 1980).
- Extend existing practices. In this process, existing techniques are adapted to apply a known technology to address the project's performance needs. This typically involves extensive computer modelling of a problem, but does not require the physical modelling and testing of full scale models as it builds on existing knowledge. For example, a structural engineer described how they had taken their normal analysis of an existing structure to forensic levels to enable a design solution to deliver 11 additional storeys to a structure (personal correspondence, reported in Jones, Martin and Winslow, 2017 Appendix H). The process was not out of the ordinary in itself, but was taken to new limits to address a client's improvement trajectory of additional floor space.
- Importing proven technologies from other sectors ('new to sector') is another quite common approach to innovation in construction, addressing the desire for performance certainty. While digital modelling and physical testing may be required to ensure the technology works appropriately in the new context, the availability of existing knowledge relating to the performance attributes of these transferable technologies significantly reduces the time needed to prove concepts. Examples discussed during the study include the use of carbon fibre beams in the support structure for the extension to the Berkeley Hotel in London (Figure 10), and the use of shock absorbent springs from the railway sector in the canopy of the Stavros Niarchos Foundation Cultural Centre (SNFCC).



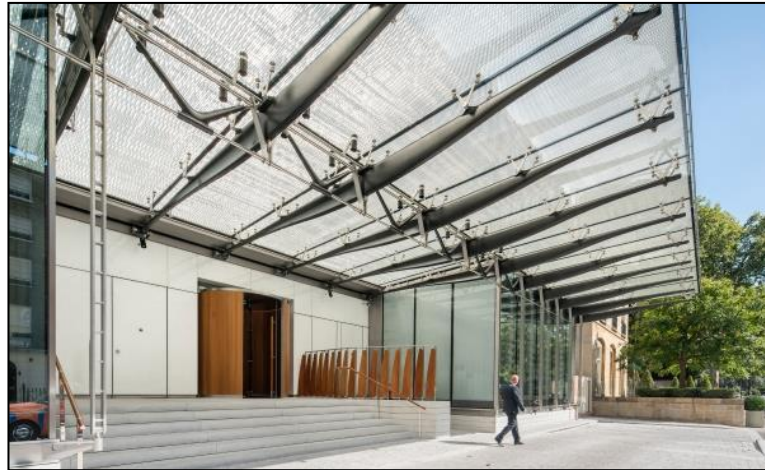


Figure 10 – Carbon fibre beams installed at the Berkeley Hotel, London.  
Photo by Joas Souza Reproduced Under License

- Radically adapt existing practices or solutions to address a performance need, exposing the solutions to new contexts. This process, a form of ‘learning by doing’, was adopted in the delivery of the SNFCC which saw ferrocement being used for a 10,000m<sup>2</sup> solar canopy (Jones et al., 2017; Jones, Martin and Winslow, 2017), a world first. In addition to the search for literature and precedents to support the material’s use, computer models, and full-scale models were also created and tested (Figure 11).



Figure 11 – Building confidence: Physical testing of a full-scale section of the SNFCC solar canopy  
(Photo Expedition Engineering, Reproduced with Permission)

- Without other suitable solutions, the need to address a project’s needs may require the invention of a new technology. Such invention / application cycles are rarely suitable for critical performance use in one-off building projects due to the need for significant lifespans and the implications of product failure (Interview 7). While infrastructure projects with longer development cycles and project durations may give scope for testing, there may be a reluctance to experiment on such mission critical projects if performance is put at risk through material failure. Old building techniques may also be re-discovered or re-appraised in light of emergent market performance needs, contributing to the re-introduction or re-purposing of discarded building techniques and technologies. ModCell, a

building system that uses straw bale and lime renders represents such a re-discovered and re-purposed technology. Data point 9 also refers to this in the context of rammed chalk.

The first two responses identified are considered to be typical means of addressing a project's performance needs, avoiding the need to introduce NMS to the project. However, this thesis is primarily concerned with impacts on expected project performances of the remaining three approaches to addressing performance needs that each require new learning to take place, so-called 'explorative innovations' (Larsson and Larsson, 2018).

#### **5.4.4 What Makes NMS too Expensive?**

The data suggest that NMS are often considered to be 'too expensive' to be used on typical construction projects (e.g. "*Any movement towards sustainability is dismissed as being pie in the sky or too expensive*" Interview II). This indicates that the elaborating impacts of NMS specification means that costs will be exceeded. However, evidence exists all around that construction projects, both literal and conceptual fabrications, might commit to deliver any building, or indeed *anything* for a price. This observation raises a question for the research that highlights the role of emergence and expectations in a project: in the context of a construction project, what is it that makes the NMS too expensive?

#### **5.5 Literature as Secondary Data Source**

The key subject areas explored through the literature are summarised in Table 5-3 below, along with illustrative references to a selection of the authors' works reviewed. The literature reviewed covers many domains, geographical and industrial scopes, recognising that the issues faced by the UK construction industry, while complex, may not be unique.

#### **5.6 Conclusions**

The data highlighted several important challenges in researching construction projects. In particular, the multi-party, contingent and emergent nature of these projects require that an assessment of the specification decision should be made *at the point of decision*. This enables the analysis of the decision's conditioning structure and influence of its elaborating impacts on actor expectations. Researchers therefore require a means to locate the specification decision to enable them to identify suitable interventions to promote NMS implementation.

Table 5-3 – Bodies of literature reviewed during the study

Discipline/Domain	Bodies of knowledge	Typical Authors / References
Judgment and decision-making	<p>Decision-making</p> <p>Problem structuring methods</p> <p>Absorptive capacity</p> <p>Behavioural decision-making:</p> <ul style="list-style-type: none"> <li>• Heuristics</li> <li>• Satisficing</li> <li>• Bounded rationality</li> </ul>	<p>Cleland and King, 1968; Schoemaker, 1982; Saaty, 1990; Suhr, 1999; Hardman, 2009; Crowley and Zentall, 2013; Parsa and Gregory, 2013</p> <p>Rosenhead, 1996; Rosenhead and Mingers, 2001; Yearworth and White, 2014</p> <p>Cohen and Levinthal, 1990; Gluch, Gustafsson and Thuvander, 2009</p> <p>Simon, 1957, 1959; Tversky and Kahneman, 1974; Todd and Gigerenzer, 2000; Sims, 2003; Hansson, 2005; Kahneman, 2011; Baddeley, 2013</p>
Decision-making in construction	<p>Material selection methodologies</p> <p>Life cycle Assessments</p> <p>Environmental Product Declarations</p> <p>Assessment Methodologies</p> <p>Barriers to adoption</p>	<p>Archer, 1969; Mackinder, 1980; Ashby et al., 2004; Ding, 2005; Emmitt, 2006; Soetanto et al., 2007; Williams and Dair, 2007; Haapio and Viitaniemi, 2008; Foxon and Pearson, 2008; Zabalza Bribián, Aranda Usón and Scarpellini, 2009; Poveda and Lipsett, 2011; Crawford, 2011; Aspinall et al., 2012; Jahan and Edwards, 2013; VillarinhoRosa and Haddad, 2013; Bakhoun and Brown, 2013; Arroyo, Tommelein and Ballard, 2014; Jato-Espino et al., 2014; Gieseckam et al., 2014; Watson, 2015</p>
Sociology	Structure and Agency	Giddens, 1984; Archer, 1995b; Shove and Walker, 2010; Porpora, 2013
Behaviour change	-	Hoffman and Henn, 2008; Michie, van Stralen and West, 2011; Sunding and Ekholm, 2015
Economics	<p>Evolutionary economics</p> <p>Institutional economics</p> <p>Problems of the commons</p>	<p>Arrow, 1962; Akerlof, 1970; Ophuls, 1977; Abernathy and Utterback, 1978; Winch, 1989; Arthur, 1989, 1994; North, 1990; Hall and Soskice, 2001; Williamson, 2008; Li, Arditi and Wang, 2013; Qian, Chan and Khalid, 2015</p>

Table 5-3 (continued) - Bodies of literature reviewed during the study

Discipline/Domain	Body of knowledge	Typical Authors / References
Construction management	Boundary spanning objects Project management Risk management Supply chain management Procurement The role of the client	Winch, 1989, 2003, 2010, 2014, 2015; Ofori, 1991; Ive, 1995; Kadehors, 1995; Akintoye and MacLeod, 1997; Edkins, 1997; Hobday, 2000; Dubois and Gadde, 2002; Bertelsen, 2004; Boyd and Chinyio, 2006; Fernie and Thorpe, 2007; Green and Schweber, 2008; Koskela, 2008; Rabeneck, 2008; Tzortzopoulos, Kagioglou and Treadaway, 2008; Brandon and Lu, 2009; Styhre and Gluch, 2010; Green, 2011; Fellows and Liu, 2012; Bygballe, Håkansson and Jahre, 2013; Floricel et al., 2014; Taroun, 2014; de Valence and Runeson, 2015; Smyth, 2018
Theories of the firm & organisation design	-	Cyert and March, 1963; Galbraith, 1977; Grant, 1996; Nooteboom, 2006
Production management	Lean and Offsite Production	Howell and Ballard, 1998; BRE, 2003; Farmer, 2016; Lean Construction Institute, 2016
Innovation theories	Transition studies The diffusion of innovations Construction innovation The role of organisation culture	Schumpeter, 1976; Henderson and Clark, 1990; Nam and Tatum, 1992; Rogers, 1995; Christensen, 1997b; Rip and Kemp, 1998; Slaughter, 1998, 2000; Winch, 1998; Gann, 2000; Geels, 2002; Blayse and Manley, 2004; Miozzo and Dewick, 2004; Dickinson et al., 2005; Bossink, 2011; Hardie, 2011; Hekkert et al., 2011; Akintoye, Goulding and Zawdie, 2012; Liu and Fellows, 2012; Loosemore, 2015; Orstavik, Dainty and Abbott, 2015; Oskam, Bossink and de Man, 2017; Ozorhon and Oral, 2017
Value	Value Management Stakeholder Management	Baier and Rescher, 1969; BSI, 2000; Spencer and Winch, 2002; Devine-Wright, Thomson and Austin, 2003; Kelly, Male and Graham, 2004; Mills, Austin and Thomson, 2006; Mills, 2013; Mills and Austin, 2014
Sense-making	Sense-making Personal construct theory	Louis, 1980; Weick, 1995; Kelly, 2003; Winch, 2015; Fellows and Liu, 2018

## 6 Assessing Interventions to Promote Novel Material Solution (NMS) Implementation in Practice

*“Designing [...] interventions on the basis of practitioner or researcher intuition rather than theory precludes the possibility of understanding the [...] processes that underlie effective interventions.”*

*Cane, O'Connor and Michie, 2012*

### 6.1 Introduction

One of the key insights from the whole data set introduced in Chapter 5 is the entirely contingent nature of the capability, opportunity, and motivation to specify and implement NMS onto a construction project. Therefore, rather than attempting to present conclusions from the observed data, Chapters 6 to 10 describe and discuss the auto-ethnographic exploration of these problems in which the researcher attempts to synthesis the data and literature through a process of sense-making. This chapter begins this process by describing the source of construction industry conservatism in material specification, material lock-in, and the findings from a review of prior proposals to overcome material lock-in. The chapter considers whether the interventions proposed in the literature will, in practice, necessarily encourage the specification and implementation of low embodied GHG NMS on projects.

### 6.2 The Challenge: Overcoming Material Lock-in in Construction

#### 6.2.1 Lock-in as the Underlying Cause of Conservative Specification

The resistance to NMS implementation has been attributed to an evolutionary process of development leading to a 'lock-in' of material specification of the dominant material solutions. Lock-in describes a situation in which businesses seeking positive profits adapt their capabilities and structures to secure a financially based competitive advantage. Over time, this evolutionary process leads to companies' “*...core competencies becom[ing] ... core rigidities*” (Unruh (2000) after Leonard-Barton (1995)). The following section explores the causes of material lock-in to dominant material solutions (DMS) in construction.

#### 6.2.2 Avoidance of Risk to Commercial Outcomes

The efficiency of the UK stock market means that listed companies that underperform compared to market expectations are at risk of their shares being sold (Hirschman, 1970; Miozzo and Dewick, 2004). This can lead to a fall in share prices, and, in turn, can make raising finance more difficult and increases the risk of takeover of those companies (Demirag, 1995). Conversely, exceeding market expectations leads to a raised share price, reduced risk of takeover and easier access to finance. These market expectations of construction companies' performance are underpinned by an assumption of the continued use of DMS on projects, meaning that there is little scope for considering NMS on projects.

Market expectations of performance are described by a rate of return (profitability) on an asset, such as shares. This expectation is set by the trade-off between risk and return for a given asset, described by the Capital Asset Pricing Model (CAPM) (Perold, 2004). Broadly, the higher the risk inherent in a share, the higher the required or expected returns. CAPM, despite some limitations, is widely used in the finance industry because of its simplicity, and is taught in introductory texts on investment appraisal (e.g. Elton, 2011). For a given asset base, there are, therefore, two broad ways of improving market perception of a company and hence to increase share prices: to deliver lower than expected risk, or higher than expected returns. A third strategy, pursued in the 1980s, was to reduce the asset base of construction companies while maintaining returns. This reduced the risk of asset redundancy in contracting companies, but accelerated the fragmentation seen today (Gann, 2000). Historically, without concerns over resource depletion or global warming, delivering improvements in risk and return over the short to medium term were the primary conventional objectives of companies listed on the stock exchange. This has important implications for company processes and policies:

- profits need to be maintained (or grown) to fund a constant (or increasing) dividend per share (Servaes et al., 2006);
- certainty of outcome is valued in the delivery of those dividends; and
- risk (uncertainty) exposure should be reduced where possible for a given outcome.

Further, input prices - wages, materials, rents – are likely to be rising through inflation. Therefore, the maintenance of constant or increasing profits requires that either income increases at a rate higher than the rate of increase in costs, or that costs fall for a given level of income. One method for achieving the necessary reduction in costs in an organisation can be brought about by specialising in a limited scope of services.

However, the standard approach to letting out construction contracts, lowest cost tendering, limits the opportunities for companies to increase income for a given contract. Companies tend to ‘buy’ work on the basis of cost competition (Utterback and Abernathy, 1975; Smyth, 2018), commoditising what is a bespoke product. Therefore, contractors are left competing on the basis of cost, efficiency and the quality of their service. The lowest tender approach to allocating work therefore encourages a reliance on the adoption of low-risk, incremental, enhancements to existing, tested products and processes (incremental improvements) to reduce costs and risks. Incremental improvements are preferred as they are based on a technology that is better understood and carries a more certain cost and risk profile (van Bueren and Broekhans, 2013) than NMS. As Mahapatra & Gustavsson (2009) explain, *“most market actors prefer to further develop or use existing technology”*. Through the need to match the bids of listed companies, unlisted contractors can be indirectly exposed to the same cost pressures.

### **6.2.3 Path-dependency and Lock-in**

Organisations develop know-how when working with construction materials. This confers market advantages by reducing future costs and uncertainty. Companies are, therefore, likely to seek to

further enhance that advantage over time by using the same material again (Arrow, 1962), constraining the use of NMS. This path-dependent development and improvement process delivers increasing returns to producers through lower costs, allowing them to secure more work (Arthur, 1989; Foxon, 2007). In turn, further path-dependent development occurs, leading to the domination of one (or more) product(s), in mature markets, and making it very difficult for new market entrants. The DMS may not necessarily be optimal from the perspective of the long-term interests of the market, consumers or society, but reflect the contingent nature of the development process (David, 1985). In structural engineering, path-dependent development appears to be one of the key reasons behind the dominance of techniques that use reinforced concrete and structural steel in all but the simplest buildings.

Over time, companies' production, processes, knowledge base and structures become increasingly aligned to delivering their products or services efficiently to meet the market expectations of risk and return using these dominant technologies. Subsequent changes to organisation structures and processes can be expensive (Christensen, 1997a), introducing uncertainty, threatening returns, and limiting the motivation to promote NMS on projects. Further, inherent risks and uncertainties make the cost-benefit calculation of NMS implementation at the project level challenging (Rip and Kemp, 1998) and specification can often be difficult to justify on a case by case basis (Appendix A). Specifiers therefore become locked-in to the DMS as a cost- and risk- effective means of project delivery to meet market expectations. In mature industries such as construction, this lock-in can extend beyond the organisation, to the industry, professional institutions, society, policy and to the education of the next generation of specialists (Simon, 1957; Unruh, 2000) as the expectations of the market are institutionalised. Lock-in is, therefore, a major hurdle to reducing embodied GHG impacts through NMS specification on individual construction projects. The industry, an accumulation of such projects, is viewed as conservative and risk-averse when considering NMS.

The construction DMS have evolved in competition to become the most risk- and cost-effective ways of delivering construction projects within the existing institutional framework (North, 1990; Jones et al., 2016). The current institutional framework, however, substantially omits consideration of embodied GHG from the decision-making process, limiting the opportunity for NMS specification on projects.

As timescales for diffusion of mitigating innovations can be expected to be measured in decades, rather than years (Grübler, Nakićenović and Victor, 1999), action in the short term is necessary to support later diffusion. In particular, as development processes in the construction industry can take many years, the opportunities for individual organisations to explore new technologies on projects are limited. With the industry also typically regarded as mature and slow to change (Gann, 1994), there is a risk that the relevant technologies may not be widely understood in time to deliver the reductions in embodied GHG emissions required by the Climate Change Act. Delaying a response would lead to an urgent need to implement unproven technologies to meet demand, or significant investment to obtain the evidence that builders need to be confident to use NMS. This would place a sudden risk or

cost burden on a highly cost constrained, risk averse industry, leading to potential business or construction failures.

### **6.3 Overcoming Material Lock-in: A Review of Interventions Promoting NMS Specification and Implementation on Projects**

#### **6.3.1 A Smörgåsbord of Interventions**

Product manufacturers and researchers who believe that a particular group of construction materials are superior to the dominant technologies are keen to understand why these products are not gaining traction (for example, Soetanto, Glass, et al., 2007; Watson et al., 2012; Persson and Grönkvist, 2015). Such research typically results in the identification of barriers to the implementation of the NMS under review at individual, organisational or institutional levels (Hoffman and Henn, 2008). Gieseke et al. (2014) provide a meta-study of such barriers. Intervention strategies are then proposed by researchers to address the observed barriers. Chan et al. (2017) have recently synthesised twelve such intervention strategies to promote a broader category of 'Green Building Technologies' (GBTs) from a review of the literature. The strategies, synthesised into four headings here, were:

- Communication, Education and Training
  - Public environmental awareness
  - More publicity through media
  - Educational programs for developers, contractors, and policy makers
  - A strengthened GBTs research and communication
  - Competent and proactive GBTs promotion teams/local authorities
  - Availability of better information on cost and benefits of GBTs
- Improving the cost / benefit ratio of implementation
  - Financial and further market-based incentives for GBTs adopters
  - Low-cost loans and subsidy from government
- Supportive regulatory context
  - Better enforcement of existing green building policies and standards
  - Mandatory governmental policies and regulations
  - Availability of institutional framework for effective implementation of GBTs
- Green rating and labelling schemes

While Chan et al.'s use of the construction industry as unit of analysis limits the direct applicability of their findings to this study (see Section 2.1.2), the strategies identified broadly reflect those observed during this research. Sections 6.3.2 to 6.3.5 now describe and critique Chan et al.'s broad intervention strategies following their consideration for use on projects during the participatory observations and the use of counterfactual thinking and thought experiments (Section 3.8). Following a review of the literature several additional intervention strategies were identified that have been proposed to support NMS implementation in specific construction projects: project integration, the use of decision support



tools for material selection, and a focus on early adopters. These interventions are discussed and critiqued in Sections 6.3.6 to 6.3.8.

### **6.3.2 Communication, Education and Training**

Many of the reported barriers to NMS implementation are described as arising from a lack of awareness, knowledge, or capability in the use of a particular approach to construction, or the importance of a particular constraint (e.g. Zhang and Canning, 2011; Smith, 2013; Jakobsen and Clausen, 2014; Watson, 2015). These reports align with the information deficit model of science communication which suggests that the dissemination of information in and of itself will enhance the scientific awareness of a community. The perspective is also in sympathy with the work of Everett Rogers (1995), who describes how the innovation specification decision-making process occurs in stages: with awareness and understanding being necessary precursors to specification. While this view is supported by some authors' findings (for example, Nesta, 2007), both Watson et al. (2012) and Jones et al. (2016) found, albeit with relatively small sample sizes, that the availability of information and training was not limiting the use of new approaches to construction. Actors were able to find appropriate solutions, specialists, information or training when required. One interviewee (VIII) demonstrated a limited technical understanding of the NMS they were working with, coupled with an absolute confidence that they could deliver the project ("*...absolutely, yeah!*") through the use of specialist subcontractors. This suggests that the search for NMS for some actors may be reactive, rather than proactive.

Giddens (1984) presents further examples from a sociological perspective of when the provision of information, education and training may not lead to the desired change:

- The information or training is related to conditions that are not relevant to the decision, trivial or uninteresting (the decision-maker is not interested in reducing embodied GHG);
- The decision-maker is not motivated to act on the new information or training (Jones et al., 2016 refers). That is, the provision of new knowledge and experience fails to address rational inattention (Section 6.3.7, below);
- The new knowledge sustains an existing situation. The information may already be known or reinforce existing perspectives;
- The information or training is presented in a way limiting its effective use; or
- The recipient of the information is unable to act upon the new information or training, lacking the opportunity to do so.

Taken together, the literature indicates that the provision of additional information and education, while necessary for NMS implementation on construction projects, may not be sufficient to motivate changes in decision-making behaviour (Gardner and Stern, 1996; Sturgis and Allum, 2004; Anderson, 2015; Jones et al., 2016). In the longer term, the introduction of education and training to the building professions may influence widespread decision-making (Hoffman and Henn, 2008). However, such long-term change is beyond the reach of an individual construction project.

Uncertainty relating to the performance attributes of materials undermines the ability to make intended rational decisions about their specification. A notable subset of interventions to provide information to specifiers promotes the use of Environmental Product Declarations (EPDs) and life cycle assessments (LCAs) to address this uncertainty. These instruments provide information about the environmental impacts of production, use and disposal of construction products. It is hoped that with the increased certainty, availability (data point C), comparability and confidence these documents bring, more decision-makers might introduce environmental performance attributes into their decision-making, influencing their solution spaces to incorporate NMS (BSI, 2006; Ortiz, Castells and Sonnemann, 2009; Crawford, 2011). However, producers of EPDs and LCAs remain free to choose the system boundaries and some of the underpinning assumptions for their impact assessments (data point H). Changes in these parameters can significantly influence outcomes (Moncaster et al., 2018). Further, reported transparency (May and Newman, 2008) and data quality issues (Cousins-Jenvey et al., 2014; Giesekam, Barrett and Taylor, 2015), limit direct comparability between assessments (“... data is really hard, and consistency is one of the biggest things that you can fall down on...” Interview 7). Indeed, one senior engineer commented:

*“Even with their limitations from a systems view perspective, I’m not sure how capable our sector is at using [LCA and EPD] in a meaningful way. Even if they were perfect, there is a lack of knowledge on how they should be used or applied ...”.*

Any additional complexity in data manipulations may cause the information to be ignored in the decision-making process (Kahneman, 2011). Some researchers attempt to address the resulting complexity by restricting the attributes in simplified LCA (Zabalza Bribián, Aranda Usón and Scarpellini, 2009). However, while simplifying the data processing, this strategy risks neglecting attributes that might be important to project stakeholders, potentially precluding an opportunity to specify an NMS.

When proposing information provision as a means to overcome lock-in at the project level the following questions must be addressed: to whom should the information and training be provided? What information or training is to be provided? How will the information be provided? When should it be presented?

### **6.3.3 Improving the Perceived Cost / Benefit Ratio of Adoption**

Another broad grouping of intervention strategies are those that encourage specifiers to consider the value drivers of stakeholders. These strategies seek to promote NMS implementation by reducing the perceived costs of implementation, or enhancing the monetary or non-monetary benefits of specifying an NMS on a construction project into decision-making. Hoffman & Henn’s (2008) identification of the latent entrepreneurial opportunities in promoting sustainable solutions is an example of this strategy. However, along with the underwriting of costs (Loosemore, 2015) or risks as a strategy to overcome lock-in, many cost-focused interventions have a narrow, commercial view of stakeholder value in the decision-making context. The costs of NMS are typically higher than dominant solutions due to the

absence of economies of scale and learning as well as network effects (Foxon, 2007). Market incentives or loans can offset these additional costs. However, they have little influence in themselves to reduce the perceptions of uncertainty, and the associated risk of failure that can lead to the anticipation of future remediation costs. Accordingly, these intervention types address a barrier to the use of NMS on financially constrained projects, but are, in themselves, considered unlikely to provide a motivation to use an NMS unless they reduce costs of NMS below those of the dominant solutions. Further, the offer of such financial assistance is typically not in the gift of a consultant on a project. One exception might be where a material supplier has links with the consultant and can tailor the cost and risk profile to the client's requirements. This is a form of vertical integration, as proposed by Levitt (2017) to address the issue of broken agency on construction projects (discussed in Section 6.3.6 below).

A related group of interventions, not considered by Chan et al., leverages the non-financial value drivers of the client, their stakeholders, and/or the project team. Where these value concerns can be made explicit, and agreed as part of a value management exercise (after BSI, 2000) these non-financial drivers might be used to provide a counterweight to the focus on current financial returns observed in many construction projects. Stakeholders can have a significant influence on decision-making, and an exploration of their conceptions of value might advance opportunities to promote NMS on construction projects (Mills, 2013; Mills and Austin, 2014). Indeed, proto-theory 4 explored exploiting this influence by developing a decision support system for specifiers.

However, in exploring a decision support tool to maximise stakeholder value<sup>5</sup>, it was soon identified that material selection is a complex, multifaceted and subjective problem (GRI, 2014; Charlson, 2015; e.g. data points A, AI), and the range of potential value drivers that project stakeholders might have were vast. Eliciting and weighting these personal and corporate drivers of value through some multi-criteria optimisation process (see also Section 6.3.7, below) would be extremely time consuming in a typically time constrained project context. It would, though, provide support to the specifier in selecting the 'best' material for the project (data point A, proto-theory 4), and would be expected to increase stakeholder satisfaction with a project. There is no guarantee, however, that such a decision support process would *necessarily* lead to the specification of a low embodied GHG solution on a project-by-project basis.

*"Our job is to do the best for our shareholders. If shareholders don't want us to innovate, we won't."*

*Data point AQ*

This remains wholly dependent upon the existence of stakeholders who value a reduction in embodied GHG and whose opinions carry sufficient weight in the project. Further, even where cost

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<sup>5</sup> Henceforth, references to organisation and PBO value drivers should be read as implicitly including a consideration of their key stakeholders' value drivers.

and risk are the value considerations targeted by NMS proposals, project participants may still have residual concerns through unfamiliarity (Interview 8).

Questions with such value-based interventions remain: which stakeholders should be consulted? At what point in the project? Which impacts should be presented to stakeholders?

#### **6.3.4 Supportive Regulatory Context**

While the use of laws, regulations and fiscal (dis)incentives could be highly effective interventions to promote the use of NMS on projects and across the industry, changes in laws and regulations can take many years to effect. They are also frequently opposed due to their political and economic implications (Webb and Harvey, 2011) and potential for unintended consequences (Davies and Oreszczyn, 2012). Therefore, these levers of change are presumed to be unavailable to project-based actors to promote NMS specification on a project-by-project basis. Further, it is noted that the Climate Change Act (2008) represents a form of regulation, but it is not driving the short to medium term behaviours to achieve the necessary decarbonisation (Giesekam, Barrett and Taylor, 2016). This is probably because the challenges of the Act are remote to those decision-makers with short-term decision horizons.

A supportive regulatory environment, however, is not limited to one that promotes NMS, or disincentivises the use of dominant solutions. Existing regulatory frameworks should be able to accommodate new technologies as they arise, that is, they are not precluded. For example, in the USA, regulations that limit the height of timber buildings are based on the presumption of the use of 'balloon frame' construction that uses highly combustible thin timber members. Cross-Laminated Timber (CLT) structures have, until very recently been limited in height by these same regulations, despite their superior fire performance. The UK typically has performance-based building standards that allow designers to adopt any construction solution as long as it achieves the performances required. This may explain why the UK has been at the forefront of the implementation of CLT on tall buildings.

#### **6.3.5 Green Rating and Labelling**

'Green' building standards are considered by some to be critical to promoting the use of new sustainable solutions (e.g Hoffman and Henn, 2008; Chan, Darko and Ameyaw, 2017). These building level sustainability rating schemes, such as the UK's BREEAM scheme or the USA's Leadership in Energy and Environmental Design (LEED) methodology have been developed in an attempt to bring definition to the abstract and context-dependent notion of 'sustainable buildings' (Ding, 2008; Haapio and Viitaniemi, 2008; Poveda and Lipsett, 2011; Berardi, 2012). They do so by providing a weighted set of environmental impacts against which new building projects are assessed (see also Section 6.3.7 below). The assessment provides an overall rating for a project that can be used to market the project. In the UK, the requirement for a particular BREEAM rating has been incorporated into planning policy in many areas, creating a potential performance gap between the

expected and deliverable performances (Rogers, 1995; Goulding, 2012). Further, the use of the BREEAM rating as a surrogate for a project's sustainability means that companies that value sustainability can call for a higher assessment rating on their projects. In this way, these schemes can be used to enhance sustainability, narrowly defined, on projects.

However, the use of such externally weighted schemes is unlikely to reflect the subjective and context specific requirements of a particular project (Aspinal et al., 2012). These schemes also consider only a limited set of the impacts of the materials used (Anderson, Shiers and Steele, 2009; Aspinal et al., 2012), with external weightings being adopted that may not adequately reflect the project context building type, or the project aspirations of project participants. For example, the use of rainwater harvesting is promoted in BREEAM for most building types. However, large sporting venues will typically use that water irregularly, but intensely, calling for vast concrete water storage facilities that may never fill. Sustainability must respond to context. Further, BREEAM in particular, currently gives insufficient weight to embodied GHG, and in particular, structural efficiency, to provoke changes in the choice of most materials. The following was a typical statement from a structural engineer:

*"I would say the key weakness of BREEAM is the approach to materials. It does nothing to promote [NMS]. You might get an innovation credit but the Green Guide is the worst at promoting [new ways of doing things]."*

Other interviewees expressed some frustration at the limitations of these rating schemes. For example:

*"... there's a disconnect there between what we're trying to do [on resource efficiency] and what BREEAM holds important."*

*Interview 3*

*"... if we were near a bus stop, we wouldn't need double glazing. Absolutely insane ..."*

*Interview II*

Further, one interviewee described how their client was interested in reducing embodied GHG, but a solution to achieve such a reduction was ultimately not used because of their overriding focus on BREEAM:

*"BREEAM is less focused on embodied energy measurements really, and they were definitely thinking about it."*

*Interview III*

But others recognised that the schemes provide a useful baseline for performances that can be lifted over time (data point AA). For example:

*".. on the plus side, if you don't have ... BREEAM, then you're going to get people like [redacted] who don't give a monkeys."*

*Interview II*

Rating and labelling schemes such as BREEAM and LEED help to define more clearly what are considered sustainable buildings for a particular time and geography, and can reflect existing priorities using appropriate weighting in their scoring schemes. Interested consultants can promote the use of these rating and labelling schemes to support the use of NMS on projects. However, unless they are specifically required by the regulatory authorities, the use of such schemes ultimately requires the consent of the client. Further, according to industry observations, the use of these rating schemes by clients is typically on the basis of achieving the best rating for a given cost, rather than necessarily seeking to push the boundaries of sustainability, though there are exceptions to this. The researcher has previously been requested to develop a costed schedule of possible ways of achieving the necessary BREEAM points to achieve the minimum acceptable rating for a project, with the ultimate selection of credits to pursue being made based on the lowest cost per point. As long as low embodied GHG materials carry a price premium and continue to be underweighted in the schema, the use of such rating schemes alone is unlikely to promote NMS use on a project-by-project basis.

### **6.3.6 Promoting Project Integration**

The considerable fragmentation of the industry (data point AW) has led to a position of broken agency (Egan, 1998; Sheffer and Levitt, 2010). That is, clients and their project teams frequently have different incentives and motivations to deliver the project (data point D), meaning that the construction project requires the coordination or re-integration of the perspectives of many different parties. This is typically achieved through procurement contracts and the development of supply chains. While these coordination interventions are typically not available to designers seeking to promote NMS, the (re-) integration of project teams and supply chains is held out as having potential for enhancing the rate of innovation implementation on construction projects (Hoffman and Henn, 2008; Sheffer and Levitt, 2010; Sheffer, 2011). Related interventions propose Integrated Project Delivery (IPD), integration of the supply chain (Gann and Salter, 2000; Zimmerman, 2007), and the use of Special Purpose Vehicles (SPV) – companies established for the sole purpose of project delivery – and early contractor involvement (Miller et al., 2009; data points I, AS) as ways to enhance productivity, encourage innovation and NMS specification. These strategies are driven by the early engagement of the organisation at the head of the supply chain (after Paulson, 1976), be that the client or contractor, and their clear articulation of their objectives for a project.

However, the success of these interventions both in promoting NMS implementation is contingent upon the objectives of the organisation directing the performance of supply chain or SPV (after Briscoe et al., 2004). If they have no overarching interest in reducing embodied GHG, attempts in the supply chain to specify NMS are likely to fail, in particular when they conflict with the objectives of the client or other supply chain members.

### **6.3.7 Improving Decision-making on Construction Projects**

*“There’s always going to be some holistic, slightly random person who makes a decision at the end...”*

*Interview 4*

#### 6.3.7.1 *How are Decisions Improved?*

Decision support intervention strategies aim to overcome the “*non-linear, unsystematic and reactive*” decision-making in construction (Soetanto, Glass, et al., 2007) and assist in addressing bounded rationality, rational inattention and biases in decision-making. Three methods have been synthesised from the literature for achieving this: ensuring that the decision is optimised rather than satisficed, ensuring that specifiers are aware of desirable solutions, and requiring, or encouraging the use of new constraining attributes in shaping decisions. These methods are each discussed now.

#### 6.3.7.2 *Optimising Rather Than Satisficing*

Decision-making on construction projects can be considered from both a normative (rational and optimal decisions) and descriptive (actual and real world decisions) perspective (Hansson, 2005). Expected Utility Theory (EUT) is the current major normative decision-making paradigm (Schoemaker, 1982). Gilovic et al. (2002) describe how an ‘optimal’ specification decision, as described by EUT, should consider the objectively determined relative importance of all impacts, now and in the future, of every possible decision. This requires an unbounded rationality. The construction project is, however, a complex, emergent, real-world construct, far removed from the EUT’s mathematically attractive “*small-world*” scenarios (Savage, 1954). Further, in the face of bounded rationality, humans in the real world tend to satisfice (Simon, 1955) rather than optimise. That is, specifiers select acceptable solutions that meet a limited number of criteria that they consider to be important to their decision, driven by their knowledge, experience and their interpretation of the project context. Satisficing in this way delivers “*reasonable solutions to real world problems*” (Simon, 1956) using what are now termed practice-based or personal heuristics, or simply rules of thumb. Based on an individual’s experience (Hardman, 2009) these heuristics can introduce bias (Tversky and Kahneman, 1974) in decisions relating to sustainable building (Hoffman and Henn, 2008).

To deliver optimised decisions, strategies typically use decision support tools to emulate the calculation methodology of EUT. By applying a weighting to reflect the perceived importance of a subset of material attributes and impacts, and scoring each material solution in each attribute category, decisions are deemed to be more rational and unbiased, solution spaces are more accurately defined. Operational research (Ashby et al., 2004), neural networks (Ballal and Sher, 2003) and agent-based modelling (Xue et al., 2005), each promote the use of n-dimensional weighted decision boundaries, from which preferred Pareto optimal outcomes can be identified and selected (Eskelinen and Miettinen, 2012). Such multi-criteria or multi-objective optimisation tools are well represented in the literature (reviewed in Jato-Espino et al., 2014). Alternative, but related decision support tools include Quality Function Deployment (Kamara, Anumba and Evbuomwan, 1997) and Choosing by Advantages (Suhr, 1999; Arroyo, 2014). These decision support tools show potential for use in exploring limited option decisions, but can become unwieldy when exploring large numbers of alternatives. The transparency of such decision-making processes makes for a defensible decision, though arguably it can eliminate some of the subtlety of less formalised human decision-making. These decision support tools are very sensitive to changes in weightings and attributes, which must

be carefully selected to adequately capture the value-drivers of the decision-makers, the available solutions, and other decision variables. Observations also indicated that ‘*people want to look at the balance at the end to see whether [the outcome] matches their intuition*’ (Interview 4), potentially undermining the entire process.

The weightings applied in this decision support process can be derived internally from the project context using, for example, the Analytical Hierarchy Process (AHP) (Saaty, 1990; Bakhoun and Brown, 2013), a panel of specialists (such as participatory event G), or value workshops (BSI, 2000). This ensures that the priorities of the project and project stakeholders are reflected in the decision-making process (see 6.3.3 above). There is some evidence that appropriate use of such tools on projects can encourage NMS specification (Arroyo, 2014; Jato-Espino et al., 2014). However, it is unclear whether this is due to the incorporation of wider conceptions of value, rather than the use of decision support tools *per se*. Alternatively, external weighting schemes can be adopted to support decisions. However, external weighting schemes typically reflect industry experts’ perceptions of current and future societal needs, rather than the needs of the project (Satterfield et al., 2009). The use of externally defined weightings, in particular, may lead to the use of low embodied GHG NMS on a project, because academics might be less concerned with short-term commercial outcomes.

The question of weightings for delivering ‘optimised’ decisions then falls between two compromised positions: adopting an external scheme is relatively straightforward but can lead to solutions that are inappropriate for the project and project context, and hence be rejected. Adopting a more time-consuming, internal weighting process may provide good project-based outcomes, but fail to reflect broader societal requirements – in this case the reduction of embodied GHG. Further, the explorations of optimised decisions are only steps towards optimisation, and remain bounded by the interests of those defining the problem. A challenge remains as to how the various participants’ value judgments are reflected in the final weighting scheme.

#### 6.3.7.3 Ensuring That Novel Material Solutions (NMS) are Considered

Some decision support tools also seek to ensure that NMS are considered in the process of decision-making, thereby increasing the likelihood of their inclusion in the solution space. For example, Watson’s (2015) doctoral thesis incorporated information on ‘low impact building materials’ (LIBM, such as bamboo, cardboard hemp-lime and rammed earth) into a multi-criteria decision tool to drive LIBM selection. It is interesting to note, however, that the examples provided of the selection tool in use present an assessment of a limited list of typical structural solutions, indicating that Watson’s low impact building materials have been previously precluded from the project’s defined solution space: for example: “*The building had already been chosen as being constructed from concrete primarily because of the geometry...*”, and, “*The hospital has been planned on an 8.4m grid system due to architectural constraints and space planning...*”, precluding many structural options (Watson, 2015). It is only in a project for the Eden Project, a botanical garden, that a wider range of lower impact solutions are considered, suggesting that the client may have a significant influence in material selection, and that search is responsive to client requirements.



Similarly, Granta Design's Materials Universe ([www.grantadesign.com](http://www.grantadesign.com)) provides a visual optimisation tool, incorporating a large data set for many materials. While the Granta tool is aimed primarily at manufacturers it is hoped that future iterations of this tool will allow construction teams to explore more product specific assessments. In the meantime, other commercial websites, such as Specifiedby ([www.specifiedby.com](http://www.specifiedby.com)), have begun the process of collating and presenting a searchable database of construction product specific data. However, as described in Section 6.3.2, the availability of information does not, of itself, necessarily lead to NMS specification. There must be a corresponding motivation to use an NMS.

#### *6.3.7.4 Requiring or Encouraging the Use of New Decision Variables*

The final means of improving decision-making identified is to ensure that all potential decision variables are taken into account when making the specification decision, that is, extending the horizons of the decision (Hansson, 2005). The introduction of new decision criteria for example, limits to embodied GHG, may exclude existing dominant solutions from the set of possible solutions, presenting an opportunity to specify NMS that can address the constraints. This process can be achieved through the inclusion of variables 'out-of-the-box' in a pre-designed decision support tool (such as BREEAM or LEED, Section 6.3.5), by encouraging decision-makers to incorporate them through priming or framing (Michie and West, 2013), or by exploring the value drivers of external stakeholder groups affected by the project (Section 6.3.3). However, where these decision variables are not considered important by the client, the resulting outcomes from the decision may lead to conflict in the project team.

#### *6.3.7.5 Decision Support Tools Critiqued*

Decision support tools provide a robust and transparent framework within which to incorporate new decision constraints, such as the embodied GHG of construction materials, into the decision-making process on projects. As such, they are held out as facilitating the process of NMS implementation. However, constraints and weightings incorporated into decision tools in the literature typically reflect the (temporal / spatial) concerns of the authors of the research or their subjects. Project specific variables will be related to the value drivers of the client and project team. These may not necessarily promote the use of NMS on construction projects. Further, strategies to promote better decision-making critically depend upon the availability of reliable, complete and comparable data on NMS attributes, and a well-defined and articulated set of preference weightings, either from the stakeholder group, or from an external source.

Tools supporting better decision-making also have limitations: in simplifying the complex process of defining and selecting appropriate attributes and weightings, issues can become conflated and confused (Suhr, 1999). For example, a desire for 'sustainability' may be compared against the unabstracted 'cost'. Further, many of these decision support tools ignore the decreasing returns experienced on improvements in attributes (Ding, 2008), such that heavily weighted attributes can be rewarded beyond the point of utility on a project. Some theoretical interventions attempt to address

this concern (Jahan and Edwards, 2013), but the tools developed become too complex for routine, non-specialist use (for example, Rao, 2006; Chatterjee and Chakraborty, 2012). In addition, many of the tools explored focus on technical matters, omitting or mistreating the financial and risk implications of implementation (VillarinhoRosa and Haddad, 2013), and fail to address the lack of motivation to specify NMS. Some tools do consider financial matters (e.g. Bakhoun and Brown, 2012), but treat cost as an attribute subject to optimisation, as opposed to a constraint on the decision which is observed as being more typical.

Sustainability is ultimately context specific. Only a detailed consideration of the project needs, context, and client value drivers can determine what can be considered an appropriate solution for a particular project. Uncritically adopting external weighting schemes ignores the context in which a project is being developed and may lead to inappropriate decisions being taken. Further, strategies using external weightings typically address only a limited subset of attributes. Consequently attributes of interest to stakeholder groups might be omitted from the decision. Rationality is extended, but remains bounded.

Decision support tools may not necessarily move a particular construction project towards NMS implementation. In the first instance the client must agree to the use of a decision-making scheme that gives consideration and weight to sustainability, or be willing to invest in the process of defining the acceptable solution space. If these support tools are to be used to encourage NMS specification, a number of questions remain open: when should the tool be used? How should weightings be determined? Who in the stakeholder group should determine the weightings and attributes for inclusion? Without client engagement, is it appropriate for a consultant to infer weightings for inclusion?

### **6.3.8 Interventions Targeting Early Adopters**

A further intervention strategy, proposed by Hoffman & Henn (2008), requires that those promoting NMS seek out organisations or individuals who are 'first movers', or early adopters (Rogers, 1995). These are individuals or organisations that are typically more pre-disposed to innovate, despite the risks. This intervention strategy takes the position of product suppliers seeking to encourage the diffusion of their product across the industry, pre-supposing that there are a selection of projects into which a given product might be incorporated. From the perspective of a single project taken by this research, however, the opportunity to select the client is removed and such interventions are unavailable and discounted here.

## **6.4 Conclusion – Lack of Coordination Limiting Implementation**

Each of the strategies to overcome material lock-in described above ultimately seeks to influence the specification decision at the level of the individual decision-maker. They do so by ensuring that the decision-maker is aware of, or understands, the solution and the need for it, or that the specification decision is formed to include, and perhaps promote the NMS as a preferred solution. While it is evident that each proposed intervention *could* lead to NMS specification on construction projects, it

remains uncertain as to whether they *would* do so. To gain a better understanding of this, research must consider whether the specifier has the capability, opportunity and motivation to specify an NMS on the project in question (Michie, van Stralen and West, 2011; Jones et al., 2016)

The literature on interventions is uncoordinated; no descriptive framework is presented within which to locate the specification decision and assess these interventions. Therefore, those seeking to promote the use of NMS are unable to determine which of these strategies to adopt on the project in front of them, nor the appropriate *locus* and *tempus* to deploy each strategy to ensure NMS specification. The development of a suitable framework in which to locate the specification decision and assess the suitability of interventions would assist practitioners seeking to address the pressing need to reduce embodied GHG in construction projects.

Such a framework must address a major challenge of construction research: describing and linking the (macro) decision context that influences so much of construction decision-making, to the (micro) levers of change influencing the behaviour of the decision-maker. This perspective is supported by research into behaviour change that demonstrates the importance of exploring in detail the context within which (health related) interventions are to be introduced (Michie, van Stralen and West, 2011). This applies equally to decision-making in the construction project, despite the additional complexity of that context. Therefore, to increase the chances of a successful intervention to promote NMS specification, there should be clarity as to the context, impact and aims of an intervention.

The previous sections have identified the primary challenges to the development of such a framework:

- When considering the role and qualities of elaboration or emergence, time is implicitly involved (Danermark, Ekstrom and Jakobsen, 2002; Winch, 2018). Descriptive models of the construction project must be *dynamic* and account for this emergence.
- Researchers should be able to *locate* specification decisions in the nested, hierarchical conditioning structure within which project decisions are taken (cf. Winch, 1998; Bossink, 2011).
- The framework should allow researchers to assess the influence of decisions' conditioning structures at the point of the exercise of agency, the individual NMS specification decision. This will enable the assessment of the elaborating impacts of the decision's, enabling the selection of case-appropriate interventions.
- Any attempt to describe the specification decision context should be *flexible*, and all-encompassing, permitting exploration of any potential project circumstance, allowing for multiple procurement routes and project structures, client types etc..

A suitable coordinating framework should, therefore, provide a means to locate the specification decision in question in the broader project context, to analyse its contingent, emergent conditioning structure and resulting elaborating impacts. The next chapter adopts these four selection criteria in the search for a suitable model of the construction project in which to locate individual project decisions.

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## **7 Locating the Specification Decision: The Search for a Coordinating Model of the Construction Project**

### **7.1 Introduction**

Chapter 6 highlighted the need for an organising framework in which to locate the specification decision, and to allow the assessment of its conditioning structure and elaborating impacts. This chapter now describes the search for a suitable model in the literature on which to build such a framework. The following sections briefly review the literature that presents perspectives on the construction project. The suitability of the latter for use as a model of the construction project in this research is critiqued with reference to the selection criteria developed in Chapter 6.

### **7.2 Projects as Structural Networks of Contracts or Relationships**

In practice, construction projects are typically represented by diagrams of the organisational, project team or contractual structures of a project, describing the relationships between actors in that project. The aim of these descriptions is to provide project managers and team members with an understanding of the prevailing reporting, governance and/or control requirements of the project. That is, they present a static perspective of certain contextual conditions, structuring decisions, rather than exploring how these structures may influence decision-maker agency. Such static representations of projects have relatively little analytical or explanatory value for this research. They do not aim to describe which decisions should be influenced by interventions, how, and at what point in time. However, these models can provide useful, if partial, information aiding understanding of the authority hierarchy within which decisions are being taken on a project.

Structure charts are described anew for each project, and do not typically explore the broader project contexts or individual decisions. To do so would be unwieldy and stand in the way of their project delivery purpose. However, the simplifications that make the diagram useful, in practice mask the underlying complexity of the project and decision contexts. This resulting representation is often simplistic and ambiguous: an arrow leading from one box to another can represent a myriad of rules, routines, or relationships and is open to a wide variety of interpretations. Further, such organisation structure charts aggregate actors into units and do not necessarily reflect the ability of an individual actor to influence the outcome of a given project or decision (Pryke, 2012). A designer at the lowest level of a reporting hierarchy may still attempt to make specification decisions reflecting their own value concerns. Subject to the criticality, impact or alignment of the decision with project requirements (cf. rational inattention, Section 2.1.3), these decisions may still be incorporated into the final project.

Pryke (2012) extends this organisational analysis through the application of Social Network Analysis (SNA). The analysis, informed by questionnaires and interviews, is undertaken to provide a visual means of exploring the suitability of the governance structures in specific projects, in light of the uncovered social and information networks. As with structure charts, the task of project analysis and

description is undertaken anew for each project, limiting the ability to generalise. The analysis leads to the production of several social network diagrams (e.g. Figure 12) that describe the relationships and information flows occurring in each of the identified networks. The diagrams relate to different aspects of that specific project, for example formal contractual relationships, cost management, progress management, and design development. These diagrams are then used to diagnose potential governance problems in the project, such as discrepancies between contractual and instruction networks (e.g. Pryke, 2012, p. 156). Each of these aspects of the project has an important influence on decision-making in the construction project, so an understanding of the structural conditioning created through the analysis is useful, but ultimately incomplete.

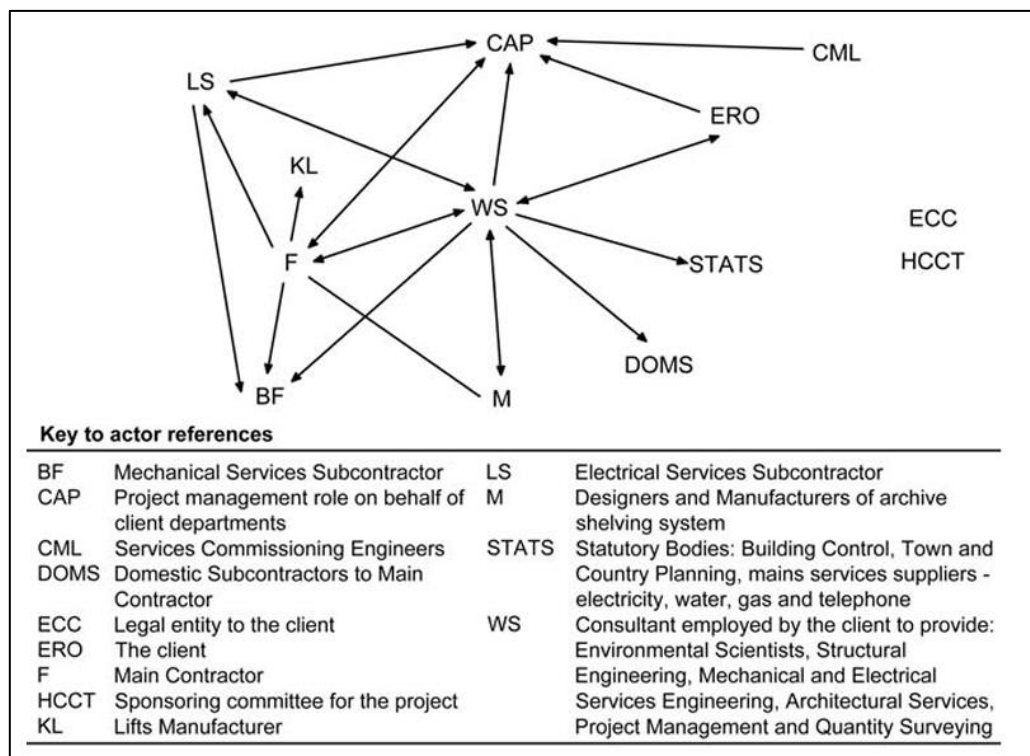


Figure 12 – Social Network Analysis (SNA) – Example design development network  
(Reproduced, with permission, from Pryke 2012)

While Pryke recognises that the project context varies from project to project, rather than embracing the associated contingency, he assumes that many of the network variables are controlled, being unconnected to information exchange. Of particular interest is the setting aside of the client organisation type, culture, and “*other environmental issues*”, each of which can have an effect on project innovation outturns (e.g. Hartmann, 2006; Loosemore, 2015). Further, the analysis of the networks presented are again static rather than dynamic, presuming that all relevant appointments have been made and these relationships remain fixed for the duration of the project. This conflicts with the observed gradual growth of projects from a few key actors to a full team and supply chain over time, and the novation of contracts that occurs under certain procurement routes.

It is notable that despite setting out to explore social relations and information flows, the analysis presented by Pryke focuses on roles, rather than the individual, assuming that individuals, roles and

organisations have perfectly aligned aims, objectives and values. As described in Section 2.2.5, this can be a reasonable simplifying assumption. However, in the context of specific decisions, the agency of individuals can be critical, in particular when the individual is granted significant latitude in their decision-making. Extending social network analysis to this micro level of individual decisions, however, risks the analysis becoming overly complex, reducing the clarity of its presentation and understanding, a key requirement of SNA. The table below summarises how the SNA and related models of construction address the requirements of a framework described in Section 6.4.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... structural network	✗	✓	✗	✓

### 7.3 Construction Projects as Emergent Space

Nocker (2006) proposes viewing the construction project as an emergent social space with multiple perspectives shaping “*the crystallisation of possibilities and expectations that define the project*” for stakeholders. Describing the project in this way allows for project actors to be viewed as having agency in the construction and manipulation of that social space. Further, it allows us to conceive of the project as influenced by the varying histories (and hence sense-making perspectives, Appendix D) of multiple actors, but still subject to the control of those in positions of power. The interaction of the project actors in the social space allows the co-creation of subjective and collective meaning relating to the project, and enables a continuity of the project through the ongoing social interaction. The identity of project changes, therefore, with changing narratives of the actors involved over time. This again resonates with the subjective value judgments that individuals have of a project, and their differing expectations of the project. Seeking to understand the project as emergent social space means accepting the fluidity inherent in a project established with no structure. While the ‘story-telling’ nature of Nocker’s study has already been deemed inappropriate for the intended audience for this thesis (Section 3.6), rendering the broader approach unsuitable for use here, it is precisely the emergent, subjective, and dynamic quality that a model of the construction project must describe.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... emergent space	✓	✗	✗	✓

### 7.4 Construction Projects as Information Processing Entities

In describing the management of construction projects as “*a problem in information, or rather, a problem in the lack of information required for decision-making*”. Winch (2010) highlights how decisions on construction projects are usually made using incomplete information (proto-theory 8). Winch (2010), therefore, conceives of the project as an information processing entity, and the project delivery process as being about the “*progressive reduction of uncertainty through time*”, leading to

information's "*progressive embodiment in a physical asset*" (Winch, 2010). While accepting the premise that uncertainty on construction projects does reduce over time, and the Carnegie School's position that organisations are essentially information processing systems, for the purposes of this thesis, this analysis is limited on three counts. First, the unit of analysis adopted in this perspective is the project, rather than the decisions made during the course of the project. This mitigates against locating and analysing the specification decision using Winch's model. Second, the decision-making necessary to reduce uncertainty is informed by more than simply information. It is also influenced, for example, by the decision context, by human biases of loss aversion, the 'availability' and 'anchoring and adjustment' heuristics (Tversky and Kahneman, 1974) and the creativity implicit in the design process. Third, the availability of information is necessary, but not sufficient to promote change: information in and of itself lacks agency. That is, a stock of information at a given moment is an endowment of a DMU, shaping the specification decision's conditioning structure within which an actor exercises their agency.

Further, Winch conceives of information as a flow to be "*directed and enabled by the structure of the organisation*" (Winch, 2010). Indeed, the flow of information to and within an organisation facilitates learning and decision-making. However, at the moment of decision, information must be conceived of as a 'stock', that is, fixed (Styhre and Gluch, 2010). The levels of that stock result from earlier flows within the organisation, influenced by the organisation's knowledge management systems (after Egbu, 2012), and between the individual or organisation and the outside world, that is their absorptive capacity (after Cohen and Levinthal, 1990; Gluch, Gustafsson and Thuvander, 2009; Upstill-Goddard et al., 2016). At the point of decision, these stocks of information may be sufficient to reduce uncertainty to acceptable levels (Figure 13), but it is likely that residual uncertainty, and hence perceptions of risk will exist at the point of decision.

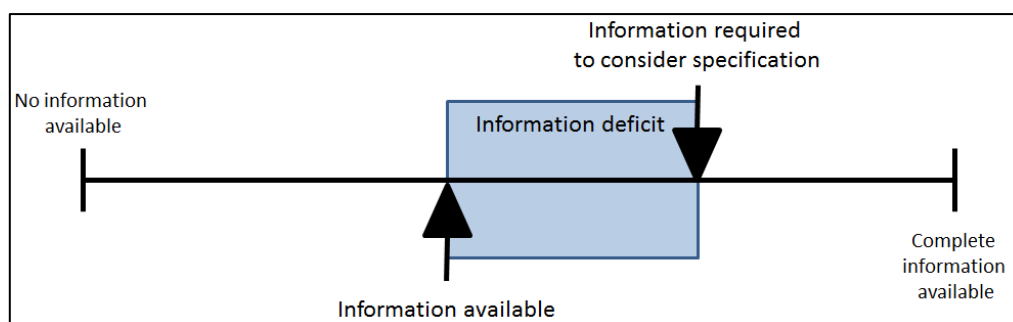


Figure 13 – Information deficit – the gap between information requirements and availability (After Galbraith, 1977)

The stock of information available at the point of decision is seen to influence NMS implementation on construction projects (Section 5.3.5). As such, any model hoping to usefully describe the construction project should incorporate a means to reflect the varying levels of information required by, held by, and available to, a project participant. Section 7.8 explores this further, describing how viewing the construction project solely in terms of information is a limiting perspective.



Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... information processing entities	✓	✗	✗	✓

### 7.5 Process Maps of Construction Projects

Mapping the processes adopted by businesses describes how an organisation directs information and materials to meet its customers' requirements (Winch and Carr, 2001). Winch & Carr adopt a business perspective of project mapping, identifying information and material flows between actors in a construction project in an attempt to develop a generic 'total project map' that describes a retail store development process. One dimension of their map represents a standardised project hierarchy (client / consultant / regulatory / main contractor / trade contractors), the other is a *standardised* project phasing based on a review of the literature. Actors within the hierarchy were grouped by role to simplify the chart. Winch & Carr's model reflects a concern with hierarchy and a dynamic dimension that are of interest to this research. Their use of hyperlinks allows users to drill down into the detail of tasks permitting an engagement with the complexity of the project. Such an approach could be expanded to cater for decisions. However, by adopting standardising assumptions relating to structure and project sequencing, the potential for describing projects that do not meet these limiting assumptions is lost. Indeed, Winch & Carr find that practice on the ground fails to follow the normative processes laid down by the organisation, reinforcing the need for a contingency based descriptive means of modelling the construction project.

Winch and Carr effectively present the construction projects of this retailer as a multi-level GANTT chart, presenting interdependent project tasks along a time line. However, rather than describing tasks, sub-processes – groupings of task that can be further explored in their own sub-chart – are aligned with the project actor grouping who undertake them, reducing the contingency further. Information and material flows are presented as finish-to-start, one-off events and the chart is silent on which decisions should be taken, and the information flows that inform those decisions. The underlying assumption behind such models of the project is that the process is linear and deterministic. Murphy et al.'s work on innovation (Murphy, Heaney and Perera, 2011; Murphy, Perera and Heaney, 2015) adopts a similar process driven perspective and therefore suffers from similar limitations for the purposes of this thesis.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... a delivery process	✗	✗	✓	✗

### 7.6 Production-based Views of Construction

The production of buildings has frequently been described as a craft process (e.g. Stinchcombe, 1959; Winch, 2003; Rabeneck, 2008), that is, buildings are created individually by a skilled labour

force. As such, the construction process has historically been largely immune to the systemisation seen in other manufacturing industries (Schumpeter, 1976). However, there are many who wish to gain the cost and inventory reducing benefits enjoyed by manufacturing organisations through the use of, for example, business process re-engineering and 'lean', or 'agile' production in the construction industry (e.g. Egan, 1998; BRE, 2003; Farmer, 2016). Indeed, during the course of the research, it seemed that this drive for efficiency, and hence competitive advantage, was the dominant industry discourse (Section 5.3.8). In discussions, industry actors - frustrated at the conservatism and lack of change in the industry - frequently drew unfavourable parallels between the construction industry and the manufacturing sectors, typically car production (e.g. data point AJ). The financial benefits that might be gained from a shift to an off-site (normatively 'better') manufacturing approach to construction would be welcomed by many actors. Indeed, such financial concerns dominated discussions on construction innovation with contractors (e.g. data point AT) leaving little room for consideration of sustainability. In proposing a shift to a manufacturing model, the industry's Farmer Review reinforces this point: "*Put simply, much of the industry does not make enough money*" (Farmer, 2016, p. 2). However, it is the pursuit of such competitive gains through incremental, path-dependent development that has led us to the position of material lock-in seen today (Jones et al., 2016).

Such process re-engineering requires the documentation of and standardisation of processes for specific production facilities, and the elimination of non-value-adding operations, restricting the exercise of agency as far as possible. As the preceding section has shown, attempts to describe the process of craft-based construction of a complex object such as a bespoke building is highly problematic. Further, in the 1980s many construction companies disinvested from owning plant to reduce their balance sheets to reduce the risk of redundancy in their asset base, and enhance ROI (Gann, 2000). Therefore, the capital investments to deliver the necessary manufacturing capacity for construction will probably need to come from elsewhere. This initial outlay will also require a consistent demand to ensure delivery on an investment business case (Levitt, 2017), and so such an approach may be better suited to housebuilding, rather than the development of bespoke buildings.

There are two key insights to take from this: the first is that while the pursuit of construction efficiency may be the dominant discourse in the industry, decisions are necessarily made on a project-by-project basis as to the appropriate degree of manufacturing for a project. The choice of production process for a building is dependent on the project team, and what they consider to be best for a particular project or site given their current knowledge, understanding, experience and personal and organisational drivers. Adopting a normative position to determine how a building should be created (as with manufacturing) ignores the complexity, uncertainty, and contingency of the construction endeavour (cf. Fernie and Thorpe, 2007 in the case of supply chain management). This requires that any model of the construction project must be capable of adaptation to accommodate the implications of the different approaches to construction that are available. The second insight is that attempting to specify NMS with GHG or resource efficiency benefits into a context that is dominated by a discourse over process and cost efficiency is likely to fail. The supply must match demand (Section 5.3.8).

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... a production process	x	(?)	(?)	x

(?) – represents an uncertainty, some descriptions might incorporate these features, but may not

## 7.7 Construction Projects as Nexus of Supply and Demand for Buildings

Rabeneck (2008) conceives of construction projects as the interface between supply (“*how to build?*”) and demand (“*what to build?*”) for buildings, moderated by regulation (Rabeneck, 2008). Working at this highly aggregated level of the building, the sum of many parts, requires an assessment of the needs of actors typically neglected in project focused research, for example, investors, regulators, the public, as well as the more typically surveyed (Rabeneck, 2008). However, a focus at this aggregate level risks losing sight of the vast complexity of the underlying product and the decisions that make up the project. As a result, it is challenging to see how this building-level perspective might be operationalised to the criteria laid out in Chapter 6 in the context of NMS specification. However, conceiving of the building as an interface between supply and demand suggests a further focus on the transactions that lead to the creation of a constructed asset, explored in Transaction Cost Economics, discussed below.

Rabeneck’s approach highlights the view that an analysis should focus on both the supply of buildings, materials and technology, and the demand for them (cf. proto-theory 9, Section 5.3.8). That is, the attributes of one should be matched with the requirements of the other. In the studies reviewed where both supply and demand are considered (e.g. Häkkinen and Belloni, 2011; Persson and Grönkvist, 2015; Ozorhon, Oral and Demirkesen, 2016), the review is not presented in the context of a coherent, actionable framework. Indeed the importance of exploring the motivations for NMS implementation themselves was the primary output from the first phase of this research, as reported in Jones et al., (2016) (reproduced in Appendix F). Green and Schweber (2008) observe that the mobilisation of the idea of middle-range theory might present an appropriate way of reconciling the tensions Rabeneck identifies between product and process.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... nexus of supply and demand for buildings	x	✓	x	✓

## 7.8 Construction Projects as a Series of Transactions

Transaction costs have been introduced previously in the context of the unit of analysis (Section 2.1.1). Despite the limitations previously identified, this section now explores the suitability of TCE (Williamson, 1985) as the basis for a descriptive model of the construction project. TCE emerged from New Institutional Economics (North, 1990) and attempts to combine economic and sociological

perspectives on industrial organisation (Winch, 1989). TCE incorporates notions of bounded rationality (Section 6.3.7) into standard economic models, recognising that individuals do not have access to complete and perfect knowledge and must make decisions in the face of uncertainty and complexity. At the point of an individual transaction between independent organisations – the interface between demand and supply – there exists an information asymmetry, leading to a risk of opportunistic behaviour against which the transacting parties must guard. Clients, in particular, are seen as being at risk of ‘hold-up’ from contractors due to the scale and asset specificity of their investment in the land and the costs of construction. Hold-up is the situation in which one party to a contract gains bargaining power over another due to an asset specific investment (Chang and Ive, 2007), and can be seen in action when contractors exploit post-contract design changes. The risk of hold-up increases when there is significant uncertainty, or incompleteness at the time of contract, a fundamental feature of construction project contracts, or if the transaction is a one-off. Li, Ardit and Wang (2015) provide a more detailed description of the sources of transaction costs on construction projects.

Adopting the firm, rather than the material purchase transaction, as the unit of analysis, Winch (1989) applies the insights from TCE to the transactions undertaken in the construction project. This unit of analysis is necessary, as the primary role that Williamson saw for TCE was the identification of the efficient boundary of the business organisation, that is, what it should make or do itself, and what it should buy in. This unit of analysis is limiting for the purposes of this study (Section 2.1 refers).

When transacting with third parties, transaction costs arise from three broad sources (Walker and Chau, 1999):

- **Search, learning and information costs.** Bounded rationality in individuals and efficiency and specialisation of purpose in organisations can lead to information deficits as to both potential market solutions to an organisation’s needs, and the adequacy of performance of those solutions. This first group of transaction costs reflect the time and costs that are anticipated in addressing any information deficit (Section 7.4) through search, information gathering and information generation. Indeed, the reliance of specifying organisations on external certification (such as those from the British Board of Agrément) represents an institutionalisation of the evidence search. Contractors typically rely on these certifications before allowing products to be used on their sites. The costs of achieving these certifications can be high (data points K, AA, observation 9), representing a barrier to market entry for NMS.
- **Bargaining costs.** Bargaining costs reflect the time and cost incurred in creating agreements for the supply of products or services between contracting parties. Typically, this reflects the time taken to strike a contract. In the construction sector, however, many of these contractual processes have been institutionalised, reducing the administrative burden.
- **Policing and enforcement costs.** This final group represents the post-installation costs anticipated from using an unknown, uncertified, or un-evidenced solution. They reflect the anticipated costs of monitoring the implemented solutions, remediation in the case of failure, and

the costs of litigation arising from such failure. During the study, it was observed that interior designers had more success in using NMS in the delivery of their services than structural engineers. This was considered to be a function of the relative impacts of a failure in these distinct services, ranging from the need (for example) to re-cover a cushion to the catastrophic. The anticipated transaction costs factored into decision-making will range similarly, making them typically less impactful on the decision supporting NMS implementation in interior design situations.

Exploring the transaction costs anticipated with NMS implementation helps to determine the additional costs that organisations face as a result of information asymmetry and uncertainty. As such, an analysis of the adoption transaction can shed light on the problems of rejection of NMS in a near perfectly competitive market (Ofori, 1991). However, beyond identifying the transaction costs that must be reduced, and the information requirements to make that happen, the theory has little to say on the processes that lead to the ‘surprise’ of NMS implementation on construction projects. In particular, transaction cost theory is explicitly silent on other project parameters of time and quality.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... a series of transactions	✓	✗	✗	✓

## 7.9 The Tavistock Institute - Construction as Socio-technical System

An early analysis of the construction industry came from the Tavistock Institute's report ‘Interdependence and Uncertainty’ (1966) in which they describe the construction project as a socio-technical system. This descriptor reflects the exploration of both the technological and social aspects of NMS implementation. However, they omit consideration of the important economic aspects. The Tavistock report focused primarily on activity within individual organisations, limiting its applicability to this study. However, the analysis is worthy of exploration as it provides further insights as to the challenges of modelling the multi-party construction project.

In an attempt to identify efficiencies in project performance the research described projects as a quantifiable, sequential network of events or activities. It highlighted how decisions made in the process of development can be constraining on later specifications (i.e. the elaboration of the solution space) (cf. Archer, 1969), and how the uncertainty over future decisions influences current decisions. Decisions should be robust, and not unduly limit outcomes. However, rather than embracing this uncertainty the Tavistock Institute were concerned to understand how the interconnected decision-making of the construction project might be made more efficient (optimised) through the use of suitable tools, more effective communication, and the development of trust.

Adopting an optimising, operational research perspective, the Institute proposed the use of the Analysis of Interconnected Decision Areas (AIDA) tool. This placed a focus on decisions that are to be made in the development of a project (type of roof, type of wall, etc.), and how the specification of

one building part limits options on the other. However, AIDA is concerned with the interdependencies *between* options and the consequences of selection efficiency on programme and budget (Boyd and Wild, 2003), rather than an exploration of decision-making itself. The research is also silent on who makes the decisions, when, and how, and presumes further that decisions are one-off items in a standard procurement type. A similar interdependence perspective was briefly considered for its suitability as a basis for this research. However, as with the Tavistock research, the formal description of interdependent design choices was deemed to be overly complex for practical use given the vast number of construction materials and solutions available.

Unfortunately, the Tavistock report suffered from two key weaknesses for the purposes of this analysis: it failed to consider other project actors, in particular the client, a key element of the construction process (Boyd and Chinyio, 2006); and the overall analysis was too abstract to apply in practice (Boyd and Wild, 2003). This abstraction highlights a challenge facing this research project. If a model is to adequately describe the entire construction project, a certain degree of abstraction is necessary. However, taking the abstraction too far limits the utility of the concepts in practice.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... socio-technical system	✓	✗	✗	✗

## 7.10 Systems Perspectives of the Construction Project

### 7.10.1 Addressing the Limitations of Linear and Static Models of Construction

The conceptions of construction described so far typically present relatively reductionist, static or deterministic views of projects. While they have each provided insight into the problem of NMS specification and implementation, and the requirements for a descriptive model of the construction project in which to locate decisions, they do not adequately deal with the complex, multi-party, emergent and adaptive nature of the construction project. Heeding the call from Allen (2008) and Green and Schweber (2008) to embrace the complexity of the built environment in research, the following sections discuss systems approaches that engage with the complexity, limiting the degree of abstraction.

### 7.10.2 Construction as Complex Dynamic System

Complex systems are those systems in which both systems and elements and the dependencies between them are important. This is distinguished from complicated systems in which the elements of a system retain a degree of independence from one another (Miller and Page, 2007). Complex systems demonstrate the characteristic of emergence (after Forrester, 1961). The behaviour of such a complex system cannot be reduced to the sum of its parts. On construction projects complex dynamic systems describe how the interdependencies in the system change over time, through the use of

feedback loops. Cleland & King (1968) provide an early exploration of the project context from the perspective of an individual (non-construction) company. Cleland & King describe the challenges faced in analysing societal problems as: interdependency, complexity and change, terms closely associated with the construction project. They extend their analysis by exploring multiple interest groups, uncertainty, conflicting objectives, and constantly evolving problems.

Cleland and King provide project management tools and methods that could be used to describe and analyse projects as complex systems. However, this systems-based concept of management is limited for the purposes of this study on two counts. The first is that their study, and much of the project management literature that follows, stems from the complex systems perspective that adopts positivist, optimising traditions of operations research (OR) and management science. These preclude contingency and adaptation, diminishing the role of actors' agency. Second, Cleland & King's analysis is drawn from a single company perspective. One might be tempted to draw parallels between the conflicts between individuals in a single organisation and between organisations to describe how project management happens in a multi-party project, but this fails to capture the important role of transaction costs in the evolution of the construction project. Indeed,

*"[T]he fragmented nature of the construction industry means that functional differentiation tends to take the form of differentiation between firms. This implies that the market relations between these firms introduces a qualitatively new element into the process of integration."*

*Winch, 1989*

The use of dynamic system analysis and mapping has undoubtedly progressed the understanding of organisations and decision-making, introducing new forms of organisation management and analysis. However, attempts to describe the context of construction project and the decisions therein are limited by the one-off nature of the project and the immense complexity thereof. There have been a number of attempts to adopt systems-based solutions to describe aspects of construction.

For example, Figure 14 presents Bajracharya's (2014) model of the construction innovation adoption value chain using systems notations, and Figure 15 shows a model of construction innovation system developed using structural analysis (Suprun et al., 2017). The resulting system diagrams present a partial view of the dynamic influences on construction innovation, providing insight to the typical contextual influences on a decision. The intention here is not to hold these models up as prototypes, but simply to use them to demonstrate how attempts to map relatively small aspects of the construction project can become incredibly complex, very quickly, reducing their practical impact. As such these individual models are presented without detailed critique.

Given this complexity, attempts to model the construction project by describing each context-dependent project decision across multiple organisations and multiple decisions at the requisite level of detail would prove unwieldy. Indeed, given the multiplicity of potential procurement and contractual structures, undertaking such mapping on a project-by-project basis would seem unfeasible, and, lacking generalisability, rather redundant. Further, while these systems-based

analyses can describe the influences on particular decisions (+ / - correlations between nodes in Figure 14, for example), they are unable to describe the regulated requirements, such as maxima or minima that are necessary to adequately define how a solution space is constrained by a particular relationship.

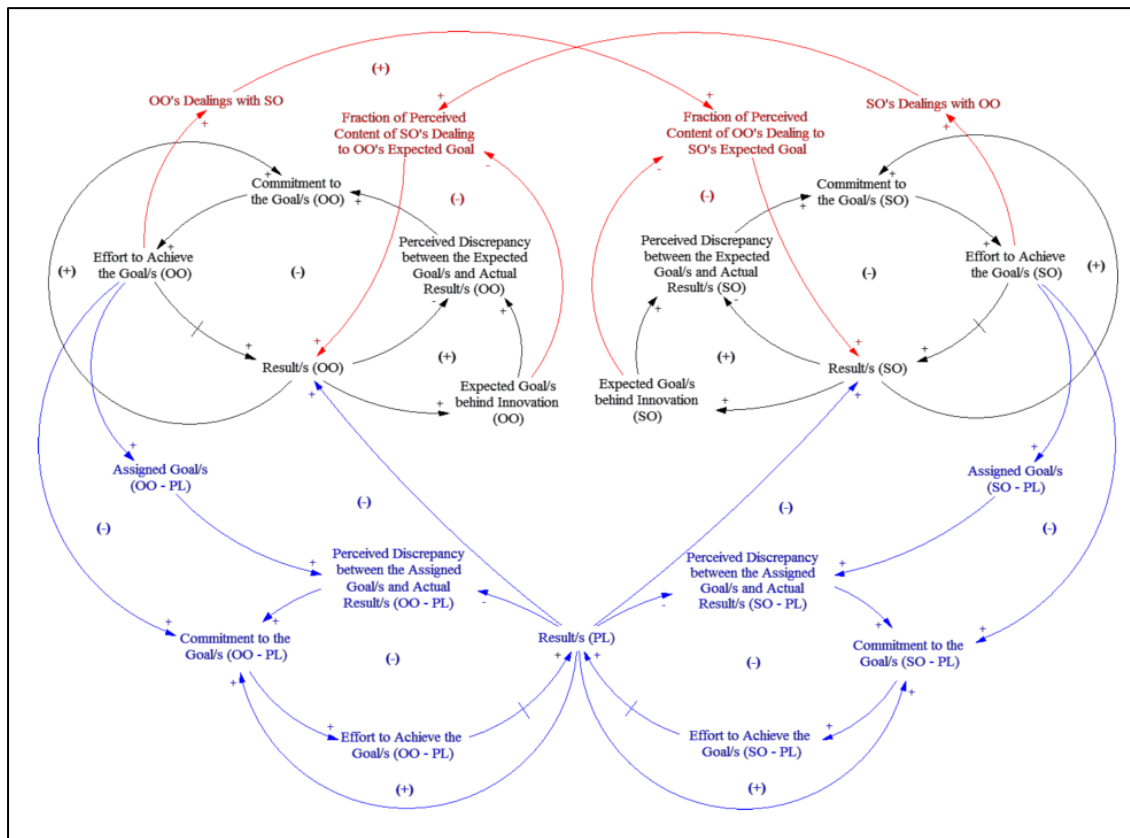


Figure 14 – Systems representation of the innovation value chain.  
Bajracharya's (2014). Reprinted by permission.

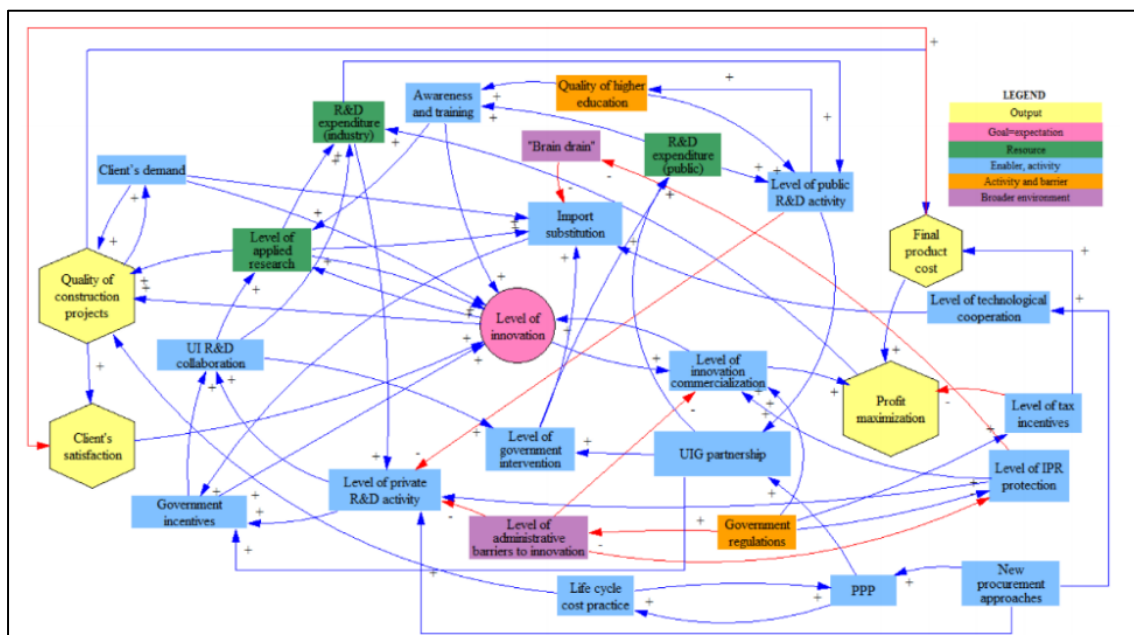


Figure 15 – Systems model of a construction innovation system.  
Suprun et al. (2017). Reproduced with permission.



While clearly dynamic in nature, complex system models, such as Bajracharya's, cannot fully reflect the interdependency of uncertain and emergent decisions as described by the Tavistock group. For example, without a complete AIDA model of interdependencies, how could a systems model describe how the selection of a liquid applied roof waterproofing membrane influences the solutions that could be used for waterproofing an upstand? Neither do such dynamic systems approaches deal with incomplete contracts, or the changing requirements that are a fundamental characteristic of the construction project. Finally, from a purely practical perspective, the presentation of these complex system models was deemed confusing and practically unhelpful by the project sponsors.

Describing the construction project as a dynamic system highlights another of the challenges in describing construction projects: they are an open system in continuous motion (Wasson, 2006). The dynamic systems approach to address this "*messiness*" is to reduce a large part of a complex problem to a simple output that can be used in decision-making (Cleland and King, 1968). That is, the decision becomes defined by closing the system so that it becomes manageable using typical OR tools, or the decision is redefined to allow a consensus solution to be developed (Rosenhead, 1996).

However, the conditions under which these OR solutions are likely to be suitable are those in which there are uncontentious activities, controlled by a unitary authority (Rosenhead, 1996), very unlike construction. Section 6.2 has already described how adopting this bounded analytical approach in a project-based open system risks omitting key elements of the problem from analysis. Further, where individuals have conflicting views, and are required to negotiate to reach agreement, complex (but unambiguous) mathematical models and 'black-box' algorithms proposed by OR solutions tend to get in the way of reaching a solution (Rosenhead, 1996). In the face of such complexity, there may be insufficient agreement as to the problem that systems analysis is trying to address.

For simplicity, many system dynamic models restrict themselves to a single level of analysis. For example, Surpun et al. (2017) explore the, broadly, external structural influences on innovativeness, while Bajracharya explores the construction value cycle at an organisational level. While they do incorporate two organisations in their analysis, the starting point of their analysis presumes a repeated learning cycle that one does not have on construction projects. These examples reflect the challenges researchers face in crossing the levels of the nested hierarchy in which construction projects evolve. By exploring only a single level of the project hierarchy, material influences on the decision might be overlooked, such as personal biases. The proposed focus on the NMS specification decision, through the lens of conditioning structure, agency and subsequent elaboration, aim to facilitate both a vertical and horizontal exploration of the problem.

One notable dynamic model of the construction project that attempts to shift from a horizontal to a vertical analysis is Bossink's (2011) examination of environmentally sustainable innovation (Figure 16). Following early insights from Winch (1998) on the hierarchical and overlapping nature of the construction project, Bossink integrates the results from a series of case studies into a nested model of sustainable innovation management. The model locates roles (see Section 7.2 for the problems in the use of roles) in teams and then organisations that operate in a broader context. This multi-level

perspective echoes the project contexts observed and described in practice. These teams and organisations then enter into cooperative projects indicated by the p-arrows in Figure 16, influenced or instigated by international issues, such as climate change, government policy or other organisational drivers for innovation. Bossink then describes how innovation at any of the levels can be influenced by developments on another level, reinforcing the need for specificity in the description and application of interventions.

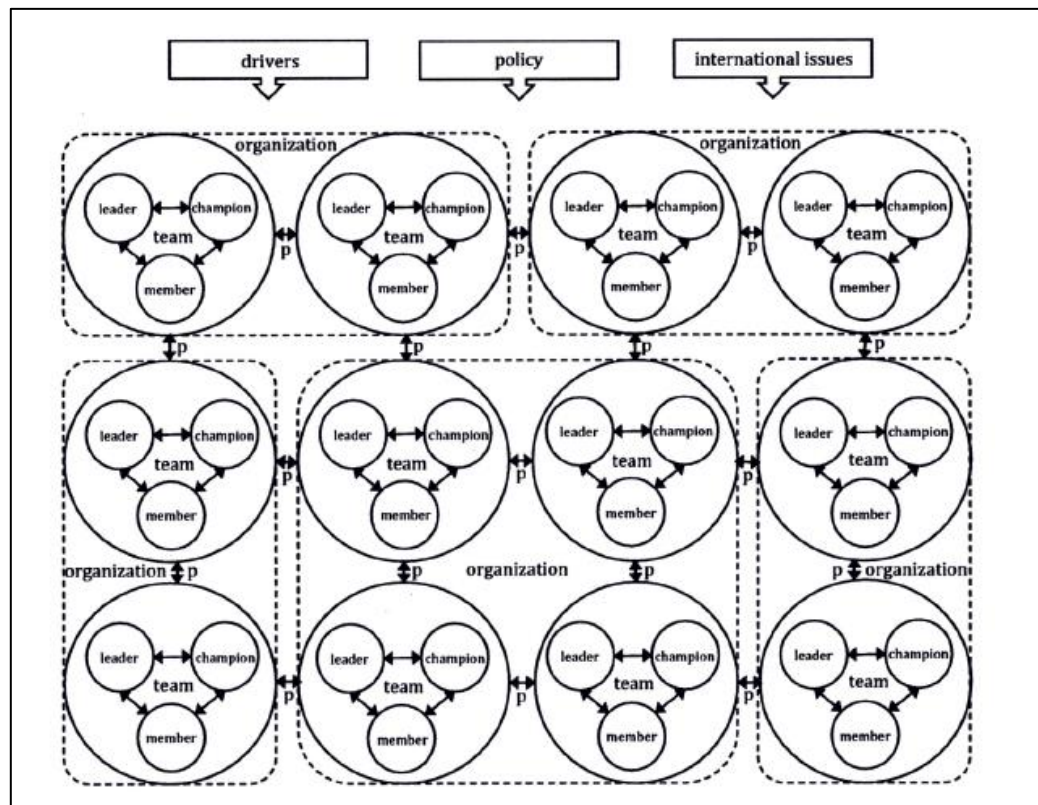


Figure 16 – Integrated model of environmentally sustainable innovation management  
Reproduced with permission from Bossink (2011).

However, the descriptive power that Bossink gains by analysing the project as vertical, nested, hierarchy is tempered by the omission of a dynamic element in the study. The model says little on the role of time, uncertainty or emergence in the development of the construction project, without which explanations of both stability and change in a system are necessarily incomplete (Sorrell, 2018).

Further, the model appears to underplay the importance of the client and client brief in promoting innovation in the construction project, presenting the client as simply another project organisation. The construction management literature describes how the role of the client as sponsor of innovation is qualitatively different from other PBOs (e.g. Brandon and Lu, 2009; Widén, 2017). This limited emphasis on the client may reflect the roots of Bossink's study in the housing market, where there is typically no singular client, merely a market profile of demand to be met. However, the model would benefit from the incorporation of the client within the management hierarchy.

### 7.10.3 Construction as Complex Adaptive System

The fact that construction is a complex and *adaptive* system (Fellows and Liu, 2012) presents a further challenge to those seeking to model the construction project. Complex adaptive systems are those complex systems in which thinking actors are able to reflect on the state of the system at a decision point and react accordingly.

A typical research response to this form of organisation is to create an Agent Based Model (ABM) of the problem. ABMs are computer simulations of problem spaces in which the behaviours and interactions of the agents are described. Running the simulation, often in parallel with Monte Carlo simulations, then permits an examination of how agents might interact and what outcomes they might produce (e.g. Stanford and Molenaar, 2016). While attractive from a positivist research perspective, such modelling requires an over-simplification of the decision-making processes of individuals and organisations and the role of creativity in the design process. As with system dynamic models, the modelling necessary to adequately describe an appropriate, contextual response would require a deep understanding of the interdependencies between decisions in the construction development process. Such models are currently considered impractical.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... complex dynamic system	✓	(?)	✗	✗

### 7.10.4 Construction Innovation Literature

The large body of literature on innovation adoption in construction (Winch, 1998; Slaughter, 1998, 2000; Gann and Salter, 2000; Blayse and Manley, 2004; Park, Asce and Dulaimi, 2004; Bossink, 2011; Akintoye, Goulding and Zawdie, 2012; Bajracharya, 2014; Murphy, Perera and Heaney, 2015; Ozorhon and Oral, 2017) has much to offer the discussion on NMS implementation. However, the body of construction innovation literature as a whole is characterised by a lack of a clear holistic direction (Xue et al., 2014) and each of the models of innovation reviewed during this research are considered limited for the purposes of locating the intervention strategies identified above. Salient studies will be revisited in Chapter 9. Further, those models of innovation that do begin to explore the dynamic, emergent nature of the construction project (e.g. Murphy, Perera and Heaney, 2015) begin from the premise that an innovation is intended to be incorporated into the project. This assumption does not reflect the challenge being explored in this thesis in which an NMS is being introduced to a project sometime after the project has been established.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... complex adaptive system	(?)	(?)	✗	✗

## 7.11 The Multi-Level Perspective (MLP) on Technological Transitions

### 7.11.1 Introduction to the MLP

Noting the requirements for a decision-based model of the construction project set out in Section 6.4, this section introduces a model of the socio-technological technology transfer from the ‘transitions’ literature (Lachman, 2013) that has been used previously to describe the evolutionary nature of the technology transfer process in construction using a hierarchical construct. The ‘Multi-Level Perspective on Technology Transitions’ (MLP) studies innovation diffusion at a societal level, rather than specific instances of technology implementation on projects. However, extending the MLP analysis to the project level provides important context for this study.

The MLP (Rip and Kemp, 1998; Geels, 2002) is a middle-range theory (Merton, 1968) that attempts to conceptualise the overall dynamics of societal level transitions between technologies (Geels, 2011). The MLP (Figure 17) provides a useful heuristic framework for exploring the socio-technical problem of technology diffusion. It views technology transitions as non-linear processes resulting from the interplay of developments at three levels: landscape; regime and niches (Chang et al., 2015).

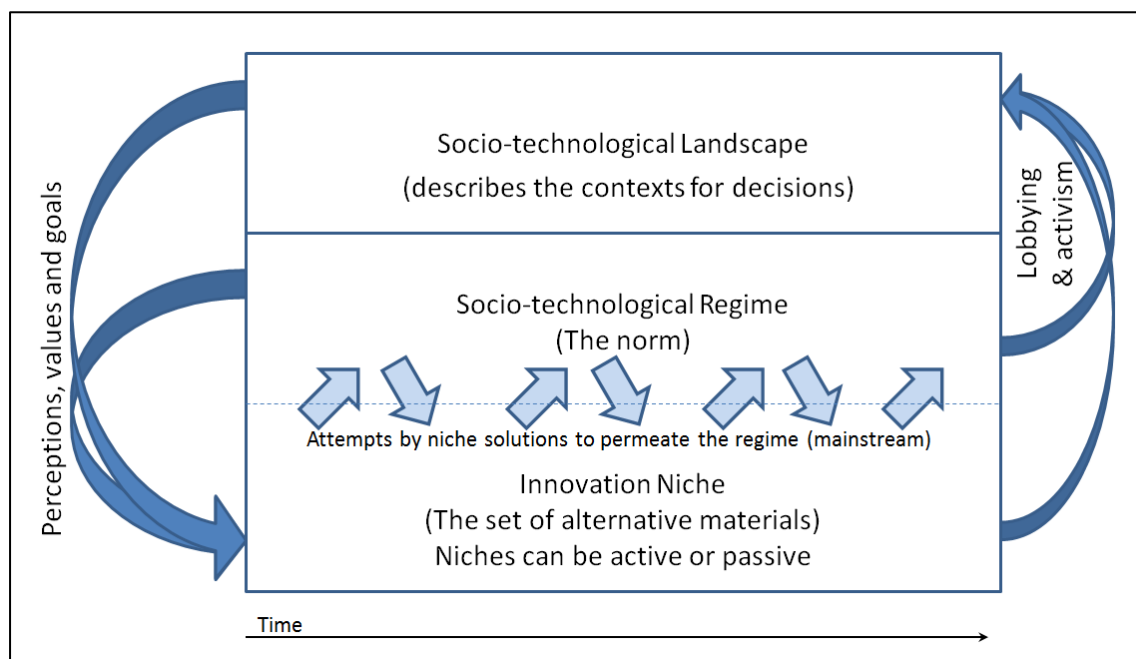


Figure 17 – The Multi-Level Perspective (MLP) on technological transitions.  
Adapted from Geels, (2002)

The ‘landscape’ describes the context within which technology implementation decisions occur, covering societal values and norms, technical and material influences as well as political ideologies. Others have conceived of this context by reference to the strategic formal and informal institutions (North, 1991) of the political, economic, social, technological, legal and environmental (PESTLE) spheres (Issa, Chang and Issa, 2010; BSI, 2014). Viewed through Archer’s lens of analytical dualism,

the landscape can be considered as part of the cultural conditioning structure within which agency is exercised.

Regimes in the MLP can be understood as the “*established practices and associated rules that stabilize existing systems*”, while niches are “*the locus for radical innovations*” (Geels, 2011) in which novel technologies are developed and protected from the selection requirements of the regime (Schot and Geels, 2008) until they can “*successfully compete within selection environments embodied in incumbent [...] regimes*” (Smith and Raven, 2012). In the context of the cost and risk sensitive construction project, this suggests that niche technologies are those that present higher risk or cost than the dominant solutions and may meet requirements for a small sector of the market. Societal level transitions, while not directly relevant to a project context, are conceived of as occurring through a process of (i) niche accumulation, or (ii) changes in the landscape and/or regime that reflect the interests of niche actors.

The landscape is described as influencing the activities and perceptions in both regime and niches. Similarly, the regime influences activity in the niches by setting the performance objectives on which they will be assessed by the wider market – the market’s improvement trajectories (after Da Silva, 2002). The regime and niches can also influence the landscape through their elaborating impacts, although to a much lesser degree and typically more slowly. However, changing the focus of the MLP to a project context, the rate of change in aspects of the conditioning structure becomes higher, more critical, and more readily influenced by project actors.

#### **7.11.2 Selection Criteria in the Niche and Regime**

The original description of the MLP proposed that regimes were separate from niches. However, after criticism, Geels (2011) accepted the utility of a flattened perspective in which both niche and regime were conceived of as practices responding to the landscape, reinforcing parallels with notions of structure and agency. However, this flattened perspective presents challenges in distinguishing niches from the regime. The MLP literature typically addresses this challenge by considering the selection criteria that each applies to decisions and technology choices (after Levinthal, 1998), reinforcing the importance of exploring these selection criteria.

When making decisions relating to the construction project, individuals will impose boundaries, or limits, to their decision, demarking what they consider is important to the decision. These limits, or decision horizons (Hansson, 2005), help to define the decision-maker’s solution space and thus acceptable solutions to a problem by determining what is included within the decision boundary. Section 5.3.4 introduced the three interdependent decision horizons observed during the course of this research that can be used to distinguish between regime and niche activity in the construction project: time, scope, and knowledge. These are now explored more fully.

The time horizon explores the willingness of a decision-maker to explore decision outcomes beyond the immediate (regime) concerns of the project (after Moffatt and Kohler, 2008). For example,

intendedly rational organisations typically plan 3-5 years in advance (Soetanto, Goodier, et al., 2007; Cheah et al., 2014, data point AS), beyond that time, planning becomes challenging due to the inherent unpredictability of the future. If an organisation were to review the impacts of climate change on their organisations over that period, they might consider it as an irrelevance (Appendix A refers). Slow, longer-term changes already underway are more likely to be factored in to plans as they are increasingly likely to impact the organisation during its planning window. The UK's public shareholding structure and focus on quarterly reporting mean that the UK's planning horizon is famously short (Plender, 2015 and participatory event AW refer). This short-term view reflects the behavioural bias of 'discounting the future' in which events that are expected to happen well into the future are typically disregarded in decision-making (Hepburn, Duncan and Papachristodoulou, 2010). Those with longer-term perspectives may factor in more temporally remote impacts to their decision (e.g. data point AS).

The second boundary observed to distinguish niche actors from regime is the scope of factors that they take into account when making their decisions. Actors who might be described as making regime-like decisions were seen to consider a very narrow scope of influences on their decisions. These influences were typically those presented by their constrained functional brief, moderated by the requirements imposed upon them by the landscape, and shaped by the improvement trajectories of the economic context within which they are operating (typically profit). Niche actors will be those that step outside of their mandated scope and consider other factors. For example, the sponsoring engineering organisation has a well-deserved reputation for producing elegant, and resource efficient structural solutions. The building functions that they address could – technically – be delivered in other ways, but by extending their scope decision boundary to include resource efficiency and aesthetics, they ensure that these are considered in their decision-making along with the (minimum) technical requirements. Finally, to identify and create elegant and resource efficient solutions, they must exploit their depth of knowledge and experience, the scope of which extends beyond the dominant technical solutions to address a particular engineering challenge.

### **7.11.3 Active and Passive Niches**

In the MLP literature, niches are described as being either actively created, or formed passively (Smith and Raven, 2012). Active niches are those that are mobilised intentionally with relaxed selection criteria to address a perceived performance gap (King, 1990) in the technology under review. For example, R&D functions within individual organisations, business incubators, universities, or activity promoted by government intervention through grants provide these active niches. In the context of the construction project, such active shielding might be considered as a supply-side intervention influencing the development of NMS, perhaps by a material producer, or a government wishing to promote novel technologies (data point AA). As this research adopts the position of construction project consultants, the related literature on the supply and diffusion of NMS has limited relevance. Passive niches, however, pre-exist any deliberate mobilisation by technology promoting actors. They can arise from consumption preferences in the market in which purchasers are willing to

forego market-focused cost and risk optimised outcomes. That is, they are willing to accept additional cost or risk in a product because of its performance attributes, or to address a geographical separation from the market for dominant solutions (Christensen, 1997b; Smith and Raven, 2012). Passive niches are demand led, creating a performance gap that dominant solutions may not be able to address. For example, concrete (using Portland cement) is a non-negative embodied GHG construction material. If a performance requirement of zero embodied GHG is set for a project that would typically use concrete in its structure, the specifiers are faced with a performance gap, creating a passive niche for a new structural solution.

#### **7.11.4 Critiques of the MLP**

As a practical, descriptive model, the MLP has, however, been subjected to criticism and challenges (e.g. Genus and Coles, 2007; Shove and Walker, 2010; Chang et al., 2017; Sorrell, 2018; Svensson and Nikoleris, 2018). In particular, authors argue that the MLP lacks the conceptual clarity to allow operationalisation (e.g. Chang et al., 2017; Svensson and Nikoleris, 2018). The imprecision of the MLP as a tool for detailed analysis is highlighted by the limited attempts to apply the MLP to the construction sector (e.g. van Bueren and Broekmans, 2013; Chang et al., 2015). Adopting a scale of analysis, and abstraction, beyond the technology specification decision, Chang et al.'s (2015) MLP analysis of the construction sector in China results in generic statements that may or may not be applicable to specific project contexts. For example, in relation to niche technologies:

*“The lack of competent architects and an integrated interdisciplinary design system is a huge challenge undermining the application of core sustainability technologies.”*

*Chang et al., 2015*

In a later paper, Chang et al. (2017) echo these concerns, arguing (after Genus and Coles, 2008) that transition analysis struggles to cater for the realities of complexity implicit in sustainability transitions. By treating ‘society’ as an abstracted whole, the agency of individual decision-makers in the process of technology transition is lost. When attempting to analyse societal transitions, such abstraction is understandable, and perhaps necessary, but ultimately unhelpful:

*“ [While grand theories] may lead to general, if not universal, laws and predictions, findings are at a level of abstraction that obscures variations on the ground and are difficult to articulate ...”*

*Green and Schweber, 2008*

Indeed, viewing of the problem of reducing embodied GHG by NMS specification through the lens of the MLP might lead to descriptions of how the regime is adapting slowly to the long-term changes perceived in the NMS niches, and that providers of niche technologies are working to get their products onto near-regime projects, with limited success because there is very little activity at the landscape level influencing the regime in the short term (after Giesekam, Barrett and Taylor, 2015). While the analysis allows broad conclusions to be drawn – for successful implementation on projects,

the characteristics of niche technologies must more closely reflect the dominant selection criteria of the regime – it tells practitioners very little about how to act in a particular project context, nor which of the interventions should be used to promote the use of given NMS on construction projects.

It is only by unpicking these abstractions, and by addressing the specificity of project contexts, the technological attributes of NMS and the value drivers of those involved with specifying technologies on construction projects that the problem of NMS implementation can be adequately explored. The next section proposes a means to address the challenges of operationalising the MLP, and to provide sufficient clarity to the conceptual underpinnings of the MLP, facilitating an exploration of the NMS specification decision in specific construction projects.

Summary: Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
	✓	✗	✗	✓

### 7.11.5 Operationalising the MLP

Adopting a morphogenetic, evolutionary perspective, the regime at any given moment can be considered to be a contingent, best-practice, response to the prevailing conditioning landscape. In a stable environment, past practice can usually be used as a guide to form expectations, leading to lock-in. A regime decision, therefore, can be considered to be one that reflects best-practice, and ‘utility’ or profit maximising in light of the prevailing landscape and available technology. However, this presumes that that landscape is uniformly perceived. A regime decision-maker can therefore be considered, at the limit, to be operating as a locked-in *Homo economicus* (Harty, 2008; Goldsmith, 2017), seeking to optimise delivery on the path dependent dominant market selection improvement trajectories of cost and risk reduction (after Jones et al., 2016). That is, their decision horizons are reduced to the absolute minimum permissible by the countervailing requirements imposed by the institutional (PESTLE) landscape contexts and the technical limitations of construction materials. As soon as a decision-maker relaxes the requirements of the regime selection criteria (for example, adding a factor of safety above that absolutely necessary for building regulation approval), or incorporating additional selection criteria (such as a required percentage of re-used materials) into their decision-making, they move away from a regime decision towards a niche.

In practice, all construction project actors will demonstrate some degree of ‘niche-ness’ in their decision-making. Some of this nicheness will result from bounded rationality, human biases and heuristics explored in the field of psychology (e.g. Gigerenzer and Gaissmaier, 2011; Kahneman, 2011), behavioural economics and finance (Baddeley, 2013). Others, however, will result from emergent project contexts, shaping a DMU’s solution space, or from individuals exercising their agency pursuing their own (non-regime based) conceptions of value, resulting in perceived performance gaps. Individual decision-makers can, therefore, be conceived of as making their decisions in a more or less regime-like manner, depending upon the influence of their three decision



horizons (Section 7.11.2) on their solution space. There will be those individuals whose decisions are almost imperceptibly different from regime decisions, such as (for example) developers of speculative warehousing, and those whose decisions might be dramatically influenced by other niche-like concerns.

*“...An awful lot of engineers [...] think their job is just to process [the building] through the code and put some sizes and things to it. That is hopeless for trying to do anything like we were doing ...”*

*Interview 5*

An example of the output from non-regime decision criteria being applied to decision-making is the University of East Anglia's Enterprise Centre which incorporates timber, thatch, and low embodied GHG concrete. The decision horizons of the project team extend significantly beyond the minimum required by the regime.

By conceiving of the regime specification decision as a contingent, profit-maximising response to the landscape, it has become clear that, outside of theory, there can be no unitary regime when considering construction projects. Each decision must be explored on its own merits.

#### **7.11.6 Creating Passive Niches**

The preceding analysis has implicitly conceived of a specification decision's conditioning structure within which a decision-maker exercises their agency, as static. However, this conditioning structure is dynamic (Archer, 1995a). Sometimes these changes may be imperceptible due to their slow pace, others may happen more quickly. Three broad categories of events have been identified that cause changes in the landscape (Driel and Schot, 2005), each with an associated influence on the exercise of agency and the setting of objectives:

- rapid external shocks, such as wars or fluctuations in the price of oil;
- long-term changes, such as industrialisation or customer preference; and
- factors that do not change or that change only slowly, such as climate change.

The salience of each landscape change will vary from person to person, dependent on their decision horizons, influencing the urgency with which they wish to take advantage of the opportunities in, or mitigate against the risks of, landscape changes. Landscape changes, or their anticipation, create demand-led passive niches, performance gaps are established, creating the opportunity to introduce NMS onto projects. However, Lockwood (2013) explains that the risks of climate change have low saliency with the UK public, limiting any 'bottom-up' public demand for companies to build sustainably. Change to overcome lock-in, therefore, must come either from above, through laws and regulations, or from within the industry, by changing locked-in patterns of behaviour or through collaboration to

develop new industry practices<sup>6</sup>. However, as described in Section 1.3, the likelihood of specific legislation being introduced in the UK to limit embodied GHG is considered to be low.

Changes, or anticipated changes in the landscape are reflected in the conditioning structure for specification decisions. However, project specific constraints must also be incorporated into this conditioning structure. Project constraints can change more rapidly and have a more immediate impact on a DMU's solution space. Indeed, as Archer (1969) describes, every decision taken on a project has the potential to form the conditioning structure for later decisions, and can lead to the formation of a passive niche. Such passive niches may be addressed by the specification of an NMS.

## 7.12 Summary: Lack of Suitable Model in the Construction Management Literature.

Table 7-1 provides a summary of how each of the models of the construction project presented above addresses the four criteria for this research identified in Section 6.3.8. Where a question mark is shown, this reflects that the model might be able to address the criteria, under certain conditions. Despite this uncertainty, each model reviewed was deficient in at least one other regard. Therefore, no model of, or metaphor for, the construction project reviewed during the course of the research provides a suitable starting point for the required coordinating model of the construction project.

Table 7-1 – Models of the construction project: fit with research requirements

Projects as...	Dynamic / emergent	Analysis of decision structure	Location of decision	Flexible
... structural network	✗	✓	✗	✓
... emergent space	✓	✗	✗	✓
... information processing entities	✓	✗	✗	✓
... a delivery process	✗	✗	✓	✗
... a production process	✗	(?)	(?)	✗
... nexus of supply and demand	✗	✓	✗	✓
... a series of transactions	✓	✗	✗	✓
... socio-technical system	✓	✗	✗	✗
... complex dynamic system	✓	(?)	✗	✗
... complex adaptive system	(?)	(?)	✗	✗
... niches to implement innovations	✓	✗	✗	✓

Describing the construction project as a process with linked and nested levels of activity (Section 7.5) might provide the basis for the development of a common model of the construction project. However, in exploring this possibility, Winch and Carr (2001) conclude:

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<sup>6</sup> While it is acknowledged that this three tiered approach oversimplifies the interconnected nature of the regulatory solutions available as described by a smart, networked regulatory framework (Mills et. al 2012), this thesis focuses attention on self-regulation and risk-based regulation.

*“... that a generic process protocol for the entire construction industry at a level of detail useful enough to provide the basis ‘for the standardization of deliverables and roles’ ... is probably unrealizable.”*

*Winch and Carr, 2001*

Similarly, Pryke (2012) presented a critique of several of the models discussed here, objecting to these models because either they are overly simplified and therefore not susceptible to detailed analysis, or, too complicated, rendering a description of the entire project impractical. In particular Pryke dismissed attempts to make an analysis at the level of all project decisions (or group of decisions) as being too broad. In the context of the flow charts, linear responsibility and critical path analyses that Pryke discusses, this may well be the case as it would imply an exploration of *every single* project decision. Indeed, it is difficult to conceive of a situation in which project specific analyses in this manner would be desirable, transferable or indeed feasible. It is little surprise that there is a widespread ambivalence to theory in the built environment (Green and Schweber, 2008).

The perspectives reviewed above are each a necessary abstraction of a highly complex, multi-party, open, adaptive system. However, while that abstraction allows researchers and practitioners to conceive of the construction project as a whole, the process of abstraction masks the very complexity that makes the descriptive modelling of the construction project so challenging. When the project specific context disappears, the opportunity for a rich analysis of the conditioning structure of a given project context at a particular moment in time is lost. To permit an exploration that embraces complexity using these models, research must ‘drill down’ through the various layers of abstraction. However, to do so causes the models to become overly complex and impractical. A notable exception to this high level abstraction is the exploration of transaction costs that begins from the point of an individual transaction. However, this transaction cost perspective remains one degree removed from the specification decision-making, despite costs forming one of the key constraints imposing on DMUs’ solution space in construction.

This process of drilling down through the abstractions ends with a DMU’s exercise of agency on a given decision. This thesis proposes that, rather than drilling down from the project level to identify, locate and describe each decision, a descriptive model of the construction project should *begin* from the individual decision necessary to deliver the project. By adopting the individual decision, rather than the project - a collection of decisions - as the unit of analysis, the problems brought about by abstraction are reduced. What is then required is a means of locating each decision in the context of the wider project structure, and a framework for analysing that decision that can be applied consistently across decisions. The challenge then becomes one of clarifying the conditioning structure of the decision under review at the point of decision. By locating these myriad decisions in a model incorporating the broader project context and providing a framework for their analysis, a comprehensive and coherent theoretical description of both the project and the NMS specification decision can be established.

### **7.13 Conclusions**

Chapters 6 and 7 have described the need and search for a descriptive model of the construction project to enable a more coordinated exploration of the problem of NMS implementation. The challenge for research is to develop a descriptive model that is sufficiently general to allow a description of the project as a whole, while at the same time providing a framework for the analysis of the specific. Such a model should allow researchers and practitioners to locate the specification decision and provide a framework within which they can assess interventions promoted to encourage the use of NMS on a project. No suitable model or framework has been identified during the review presented in this chapter. The next chapter addresses this gap.

## 8 Locating the Specification Decision: A New Model of the Construction Project as Decision Array

### 8.1 Introduction

#### 8.1.1 Chapter Purpose

This chapter presents a decision-based, descriptive middle-range model of the construction project ('the model') that accounts for the detailed requirements identified during the research (Objective 2), described in the preceding chapters. The model described below, developed through a process of abductive inference, combining a reflexive consideration of the data and literature, provides a framework within which the specification decision can be located. The model has evolved considerably during the research process, with numerous iterations, false starts, and theoretical dead ends. Some of the key evolutionary moments in the process of sense-making supporting the development of the model are presented in Appendix C.

#### 8.1.2 Middle-range Theories

A descriptive middle-range model of the construction project is proposed to address the challenges of linking the macro context with the individual decisions (Section 7.12). Middle-range theories are those groups of theories that are intermediate to general theories of systems, which are too broad, or abstracted, to account for empirical observation, and those detailed descriptions of specific observations that are not generalised at all. Middle-range theories are more than a mere empirical generalisation, however, and each aims to provide a degree of abstracting generalisation on a given problem while remaining close to, and accounting for, the reported empirical evidence (Merton, 1968). A middle-range theory is tested for its fruitfulness, not necessarily by its veracity as an image, but by noting the range of theoretical problems and hypotheses that it addresses (Merton, 1968). To remain applicable, such theories must strike a balance between generality and completeness (Yearworth and White, 2014).

Middle-range theorising seeks to address and integrate multiple perspectives at multiple levels of conception, setting them apart from the metaphors and models explored in Chapter 7. The model described in this chapter connects these scales by locating and exploring the individual exercise of agency (micro, decision) within the wider, emergent conditioning structure (macro, context). Middle-range theories typically begin with a simple image to act as organising principles from which inferences can be drawn, further theories developed, and hypotheses tested. Merton (1968) describes how Boyle began with an "... *image of the atmosphere as a sea of air* ..." and Gilbert with an "... *image of the earth as a magnet* ...". The aim of describing the construction project by way of a simple image or metaphor, is not new. Indeed, Chapter 7 discusses several such descriptions. As abstractions, however, they have been unable to bridge the divide from the contextual to the operational while adequately addressing the temporal.

## 8.2 A New Middle-range Theory of the Construction Project as Decision-making Array

Section 2.1.1 described how a building can be conceived of as a context-dependent series of performance attributes. In turn, the construction project can be conceived of as the process of determining and delivering the desirable performance attributes for a building-to-be. The descriptive model of the project, therefore, begins with a simple image of the construction project as a decision array, including all of the decisions needed to move a project from inception to completion (Figure 18). These decisions are the precursors to delivery, informing action. Moving from this simple, rather abstract, image of the construction project to an operative, descriptive model within which to locate specification decisions is no small step. Therefore, this chapter presents a narrative description of the model, integrating relevant literature and empirical evidence where appropriate. Chapter 9 then applies the model to describe a framework within which to assess NMS specification decisions, integrating the data and locating other bodies of construction management and construction innovation literature as appropriate.

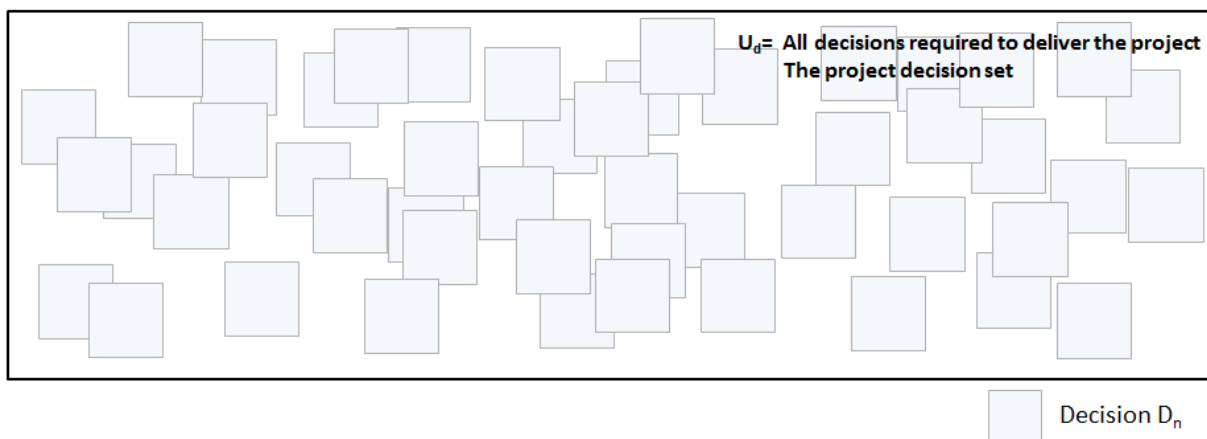


Figure 18 – The construction project conceived as decision array

Before a project is initiated, at a time  $t_{-1}$ , no project exists. To move from this state of non-existence to a completed building, a vast number of decisions must be made. The first relevant decision, taken at time  $t_0$ , is that a building project is necessary to meet some perceived performance gap (Section 7.11). The decisions required to move a given project from  $t_{-1}$  to completion, represent the universal set ( $U_d$ ) of all decisions ( $D_n$ ) for a given project. Figure 18 presents this initial image of the construction project at  $t_{-1}$  where absolutely no limits have been set to restrict what might be produced as the project has yet to be conceived. The description also begins with the assumption that all of the decisions required to deliver the building are to be undertaken by a single decision-making unit (DMU). This assumption will be relaxed as the model is developed in this chapter.

Figure 19 shows how each and every individual decision ( $D_n$ ) in a project, that is, every exercise of agency, is influenced by the contingent, emergent context (Section 5.4.1) in which it is taken. The decision then either reinforces or alters that decision context. The context's influence on the DMU's solution space is explored further below (Section 8.3). This is followed by an brief discussion relating

to the assignment of the specification decision to a DMU (Section 8.4), and an exploration of project processes following the specification proposal (Section 8.5).

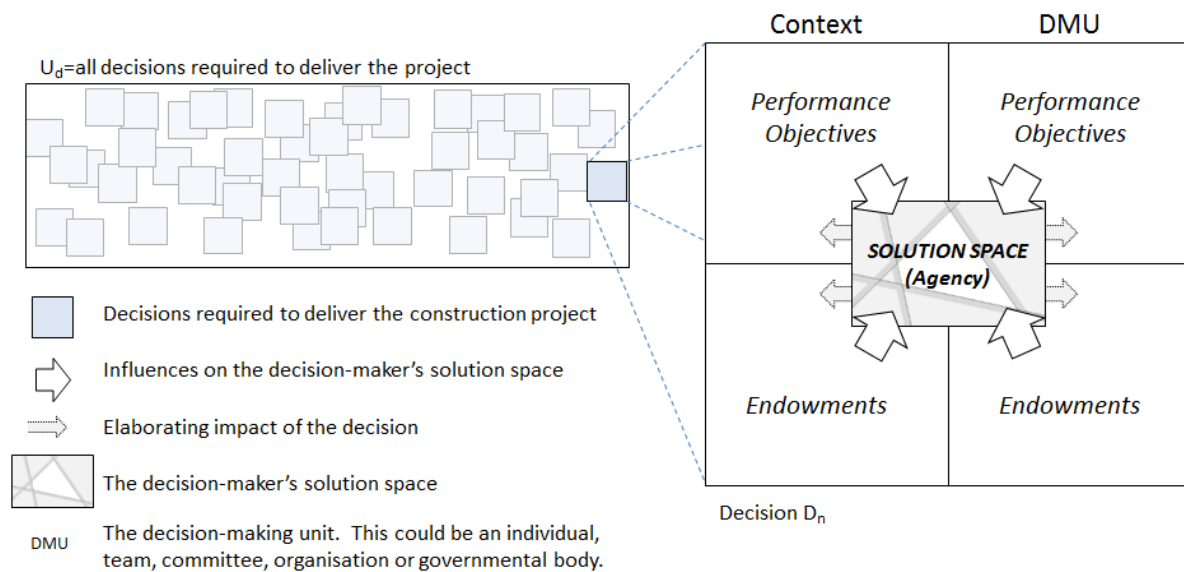


Figure 19 – Analysis of the individual decision,  $D_n$

## 8.3 The Conditioning Structure of the Decision Context

### 8.3.1 Endowments Identified in Interview and the Literature

Section 5.3 describes the endowments that were considered important to the implementation of NMS on projects in interviews (Table 5-1). An individual's endowments influence their decision-making behaviour. These endowments, fixed at the point of decision, are influenced by the DMU's prior experiences and values (after Devine-Wright, Thomson and Austin, 2003). In particular, a decision-maker's resource endowments relate to the resources over which they have authority or control, both in their personal domain, but also within the context of the PBO, and project. Similarly, other actors will also have cultural and resource endowments, influenced by their particular histories and values.

The opportunity to enhance their own (cultural or resource) endowments through participation on a project motivates the decision-maker to propose a particular set of performance objectives describing a project's process of delivery or final form. However, those other actors will also have a stock of cultural and resource endowments that they bring to bear on decisions, influencing their performance objectives (Section 5.3.4). These decisions can influence the solution space of project decisions. Further, limits to a decision-maker's endowments, such as their absorptive capacity, or history of NMS use, could restrict their solution space for a given decision or the solutions contained therein, precluding the consideration of NMS in a specification decision. The endowments influencing the NMS specification decision will be discussed in Chapter 9.

Of particular relevance to the construction project, however, are the resource endowments of time and money (Section 5.3.2), two of the arms of the 'iron triangle' of project management (Cuellar, 2009). The industry is considered to be close to perfectly competitive (Ofori, 1991), and the auctions

for construction contracts (Dyer and Kagel, 1996) typically result in time and cost budgets being trimmed to the lowest possible levels, often beyond the limits of profitability (Thaler, 1988), exacerbating the hold-up problem. Careful to moderate use of scarce resources, organisations reduce the available slack with project bids seeking competitive cost advantage, typically through incremental time and cost savings. However, the elimination of such slack leads to a tightly coupled delivery system (Dubois and Gadde, 2002), and a reduced resilience against unanticipated events and limits experimentation. The commitment of resources to a project by a PBO is explored further in Section 8.6.

### **8.3.2 Performance Objectives**

#### *8.3.2.1 Some Terms Clarified*

The following sections describe how the model conceives of the structuring of a DMU's solution space by the various project actors through an exploration of the concept of performance objectives. However, before beginning the exploration, the relationships between four inter-connected terms that support the discussion are described: decision variables, performance constraints, performance objectives and performance attributes.

#### *Decision Variables*

Decision variables represent the factors (after Suhr, 1999) that an entity might be interested in addressing in their decision-making on a project, influenced by their cultural and resource endowments and resulting conceptions of value (Section 5.3.4). For example, a company might be concerned with the capital costs of a tap. However, the number of decision variables that *could* influence a given decision is practically infinite, but can also be incredibly specific. For example, a DMU may have a concern to ensure that their specification decision has categorically no impact on the habitat of pygmy three-toed sloths<sup>7</sup>. Therefore any factor that might impact on that habitat will be a decision variable of interest to the DMU. The infinite number of potential decision variables of interest are adopted here as the universal set ( $U_v$ ) of all possible inputs to a specification decision. The number and scope of decision variables considered in a particular project decision will be dependent upon the DMU's decision horizons (Sections 5.3.4, 7.11.2), endowments (Table 5-1), and the context (broadly defined) within which the project is located (Section 6.2). As such, the set of variables to be considered on a project will be contingent on the individuals, organisations and authorities involved and project context.

#### *Performance Constraints*

Performance constraints describe the range of outcomes that a DMU would accept in relation to a particular decision variable in a given decision. These constraints will restrict the solution space for a

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<sup>7</sup> The pygmy three-toed sloth is found exclusively in the red mangroves of Isla Escudos de Veraguas. A 2012 census observed a total population of 79 (Kaviar, Shockey and Sundberg, 2012).



decision incorporating a decision variable, eliminating some solutions from consideration. For example, the tap referred to above should not cost more than £3.50. Where there are no limits imposed on a decision relating to a decision variable, the relevant decision variable is considered to be non-constraining on a DMU's solution space. On construction projects, the path-dependent process of lock-in has reduced the number of performance constraints that are typically considered by a DMU to close to the regulated minimum (Section 7.11.2). The form of these constraints can sometimes be conceived of in terms of mathematical formulations: equal to, not equal to, less than, more than, etc.. While this form of mathematical description is typically used in operational research (OR) to formally define solution spaces, they are considered inappropriate for the construction project specification decision. In part, this is due to project uncertainty, but more problematic is the non-numerical and often subjective nature of many of the performances in question, for example, aesthetic quality (e.g. Whyte, Gann and Salter, 2003).

One particular mathematical expression is often used, in relation to costs, although not expressed as such: less than or equal to. That is, limits are set to costs, but the hope for many project actors will be that the final outcome is that costs are less than budgeted (Section 5.3.2). Where a DMU's performance constraints relating to a decision variable are conceived of as an inequality (greater / less than or equal to) the decision variable can be described as an improvement trajectory for the DMU.

#### *Performance Objectives*

Performance objectives describe the extent to which a performance constraint should be binding on a decision outcome (after Suhr, 1999). (It would be okay if the tap cost a little more than £3.50). These performance objectives, discussed further in the next section, reflect a decision-maker's conceptions of value and recognise that not all performance constraints will be equally important to them.

#### *Performance Attributes*

Performance attributes are the performances demonstrated by a solution (Parrish and Tommelein, 2009) relating to particular decision variables (the tap costs £2.87). Where performance objectives might be considered to be the 'demand' for a performance, a solution's performance attributes represent their potential supply. It is important that research considers both (Section 5.4.2). Many of the performance attributes that are relevant to (locked-in) decision-making on construction projects are provided in data sheets, or the LCA of a construction product. However, as described in Section 6.3.2 these declared attributes of performance represent a limited subset of all possible attributes of a product. Indeed, if one considers that a zero impact on the habitat of the pygmy three-toed sloth represents a performance attribute, it becomes clear how the potential performance attributes required of a product or building can also be limitless.

### 8.3.2.2 Performance Objectives: Requirements, Expectations and Aspirations

Performance constraints establish limits on what can be delivered in the construction project. Observations showed how these constraints aren't always as constraining as they first seem. Sometimes budgets are exceeded, sometimes a client's enthusiasm for an innovative building is tempered when confronted with the impacts of that proposal. Not all constraints are seen as binding decision-makers to the same degree. Chapter 5 calls for a means to express the differing nature of such constraints which this section addresses. One type of constraint is provided by the UK's building regulations require that "*adequate provision shall be made to ensure that the building is stable under the likely imposed wind loading conditions*" (HMG, 2013a). This is an example of a 'must' criteria – the building 'must' be stable under the conditions described. Such criteria set non-negotiable performance constraints that must be satisfied by the project for it to be considered a success, or indeed, permitted. Such performance constraints can relate to multiple levels of the project, for example at the level of material, component, or building, as well as the project delivery process, and can arise from many sources. In his 'Choosing by Advantages' decision-making system (CBA), Suhr (1999) highlights the importance of distinguishing between such 'must' criteria that preclude unacceptable alternatives, and 'want' criteria that reflect the preferences of one or more decision-makers (Parrish and Tommelein, 2009). Similarly, in a discussion on construction theorising, Rabeneck (2008) proposes three elaborations of performance objectives (Section 7.7) relating to the attributes of a material, component or building:

- Regulated performance – akin to Suhr's 'musts';
- Desired performance – reflecting the 'needs and aspirations in terms of the qualities of the end product' (Rabeneck, 2008) – explicitly omitting the delivery process; and
- Deliverable performance – reflecting the limits of what can be provided given the pre-existing conditioning structure of the specification decision.

It is unclear whether Rabeneck intended for the word 'regulated' to be used solely in the context of formal building regulations put in place by the government, or a wider one. However, it has been observed that these 'must' criteria can also arise from clients, or other external stakeholders to the project. Therefore, to reduce the risk of ambiguity, the performance attributes that 'must', or 'won't' be present in a successful construction project will be labelled here as 'performance requirements', irrespective of their source. Rabeneck's 'desired performance' and Suhr's 'want' criteria are considered to lack the necessary gradation to reflect the applied decision criteria observed on live projects and described in interview. In practice, the strength of the 'want' for a performance can vary between expectation and aspiration, reflecting performances that should, and could be delivered on the project respectively. These criteria are also closely linked with Rabeneck's 'deliverable' performance in that they are moderated by what is practically achievable, given the other constraints on the project.

This distinction between decision criteria on projects adopted here is influenced by both the CBA decision-making system (Suhr, 1999), and the MoSCoW method of attribute prioritisation (IIBA, 2009), used in the field of software development. In the MoSCoW method, performance constraints are prioritised as those that Must, Should, Could or Won't appear in a given software release. The IIBA (2009) describe each decision criteria as follows:

- *“Must: Describes a requirement that must be satisfied in the final solution for the solution to be considered a success.*
- *Should: Represents a high-priority item that should be included in the solution if it is possible. This is often a critical requirement but one which can be satisfied in other ways if strictly necessary.*
- *Could: Describes a requirement which is considered desirable but not necessary. This will be included if time and resources permit.*
- *Won't: Represents a requirement that stakeholders have agreed will not be implemented in a given release, ...”*

In the model of the construction project presented here, 'should' items are described as 'performance expectations' while 'could' items are 'performance aspirations'. A parallel is also drawn between performance requirements and 'must' / 'won't' criteria.

The MoSCoW method is perceived to have some drawbacks, in particular the tendency for high profile, but unnecessary attributes to be prioritised at the expense of more mundane needs, such as maintenance. The modifications to the method described below are intended to address this limitation by emphasising the collective impact of performance constraints in shaping the DMU's solution space, rather than considering a simple preference ranking. Further, the method's terminology has been adapted to reflect better the observed nature of the decision criteria applied, and echo the language observed, in practice. The language adopted also introduces a temporal dimension absent in the MoSCoW method, the CBA system, and Rabeneck's analysis.

In the model, performance expectations are conceived of as those performances that a product (deliverable) or process (delivery) should demonstrate, but for which there is a limited degree of latitude in their delivery. A typical example of a project expectation is the project cost: a decision-maker might accept relatively small deviations in the total costs, but is unlikely to sign 'blank cheques' for the delivery of their project. If that latitude becomes unrestricted, that is, the relevant performance becomes non-constraining on a decision-maker's solution space, performance expectations become performance aspirations. While *“nice outcomes”* (Interview IV) these performance aspirations can be ignored in decision-making without the risk of sanction. Data point G describes a project aspiration relating to resource efficiency.

These performance requirements (R), expectations (E) and aspirations (A) (collectively, performance objectives) are presented as discrete headings. In practice, however, there will be a degree of continuity between the categories, in particular in performance expectations and aspirations. A working distinction can be drawn based on the sanction for non-performance: a failure to deliver on a

requirement would lead to project failure; a missed expectation may lead to sanction, an overlooked aspiration is unlikely to do so. Performance aspirations can also be distinguished by the presence of some form of incentive or reward scheme, rather than sanctions, to motivate the project team to deliver (Interview 7). Further, a particular decision variable can be represented by both expectation and aspiration. For example, project budgets may be set for capital costs of an element in the building, setting performance expectations. However, lower costs will likely be well received as a cost reduction is an improvement trajectory for many construction project participants. This establishes an inequality – costs will be less than (aspiration) or equal to (expectation) the budget – that will contribute to the definition of the solution space. Once performance expectations are set, the presence of aspirations over associated improvement trajectories can continue to influence decisions. For example, one interviewee described how cost reduction aspirations influenced decisions made on a project once sustainability expectations or requirements had been met.

*“We had an Ecohomes assessment done, because we were required to for building [regulations], and it came out as ‘Excellent’, without trying. So our client reduced the insulation from 100mm to 50mm to get us back down to ‘Very Good’.”*

*Interview II*

In Figure 20, a project's performance objectives are informed by a decision's conditioning structure. Similarly, they influence decision-maker's agency (Section 2.2.5.2). At  $t_1$ , this conditioning structure reflects the performance requirements, expectations and aspirations imposed by the external context on decisions relating to the project. These performance objectives will influence the solution spaces for each of the decisions on a project. It may be that particular performance objectives do not impose on the shape of a DMU's solution space for a particular decision as there are other, dominating, performance constraints. However, performance objectives are considered to always constrain a solution space to some extent.

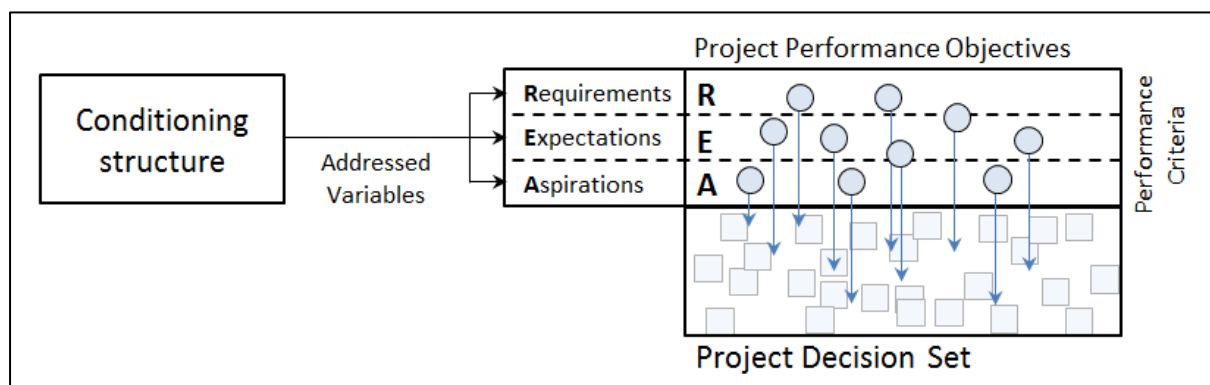


Figure 20 – The influence of performance objectives on project decision-making.

While these descriptions of performance objectives provide a degree of insight to the different types of constraints on decision-making, the description remains limited. By ignoring the sources of these performance objectives, government, societal concerns, the client, and so on, the potential sanction

for failing to meet the various performance objectives is overlooked. The next sections discusses the various sources of the performance constraints that limit what can be built on a project.

### 8.3.2.3 *The Variables Influencing NMS Specification*

#### *Context Variables*

*"The minimum statutory requirements are the maximum that most people will build to..."*

*Interview 1*

Before a particular DMU can begin to explore what they consider to be important in relation to a project, their decisions will already be constrained by the political, economic, social, technological, legal and environmental (PESTLE) context in which the decisions are to be taken (Section 6.2). Organisations and institutions exist that are interested in, and have oversight of, some of the decision variables in the universal set ( $U_v$ )<sup>8</sup>. These institutions will influence decisions taken during the development of any project subject to their oversight, potentially restricting the permissible performances of a building. For example, the UN has developed conventions and protocols addressing long-range transboundary air and water pollution, issues that require transnational coordination. However, these conventions also influence decisions made on local construction projects, through regulation by national governments. National governments and local councils also set out regulations and statements of practice that address certain decision variables insofar as they relate to the construction of new buildings.

*"Defensive strategies are adopted in the face of regulatory change."*

*Data point AT*

*"The priority is not to get prosecuted."*

*Data Point AV*

Therefore, even before the project is conceived at  $t_1$ , decision solution spaces, and hence decisions are already conditioned by the concerns of these influential external institutions. In particular, the economic system within which the development takes place will have a strong influence over the project's initiating decision. The variables of concern to these institutions will change over time, typically slowly, reflecting societal needs and concerns. Decisions are further influenced by professional institutions and social norms, meaning that certain courses of action, while not prohibited by regulation, are socially undesirable or commercially or physically impractical in particular contexts.

The issues that these external institutions - in both senses of the word - concern themselves with are termed here *context variables*, and are beyond the short-term control of the project team at  $t_0$ . They

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<sup>8</sup> To clarify, 'institutions' here refers to organisational institutions, such as the RIBA, or the UN, rather than the '...cultural rules which function as templates for the way we perceive our environment and how we act' (Kadefors, 1995). This latter description has structuralist overtones, but is considered to form, in part, the conditioning structure within which agency is exercised (Section 2.2.5.2).

can be considered akin to the landscape in the MLP (Section 7.11), and are influenced by endowments and performance objectives external to a client at  $t_0$  (Figure 19). Addressing the variables of concern to these groups provides construction organisations a license to operate, (Interview 7) transgression of the related performance objectives can lead to unrealised, dangerous, or inappropriate projects.

The project's context, therefore, addresses a significant number of variables from the universal set,  $U_v$ , establishing performance objectives that structure a decision-maker's solution space. However, even after considering these contextual performance objectives, there remain a vast number of variables or attributes that might yet be incorporated into decisions.

#### *Client Variables*

The context performance objectives form the conditions in which organisations are established and operate. Each such organisation is established to pursue a number of objectives, the nature of which is dependent – in the first instance – upon the aims and value drivers of the organisation's founders. These objectives can be amended over time as the interests of key stakeholders, often the owners, funders or members of the organisation, change, influenced by the external context in which the organisation is constituted (Mikler and Harrison, 2012). Organisations can therefore have differing missions and conceptions of value. For example, the charity WWF (data point AF) has as its primary objective:

*"The promotion of education and research by the support of studies and of educational activities and the publication of educational and scientific works thereon and by providing opportunities for such studies and activities by means of the conservation of world fauna and flora, water, soils and other natural resources"*

*Charity Commission, 2018*

However, while charities must state their charitable objectives, British company law does not require companies to declare any specific purpose beyond "...*carrying on business* ..." when they incorporate (Hutton, 2018). This phrase is adopted by the Canary Wharf Group in their Memorandum of Association (loosely, the company's constitution) implying an overarching profit seeking objective. Not for profit and social enterprises are notable exceptions to this statement. Indeed, company directors' fiduciary duties include the "*duty to promote the success of the company ... for the benefit of its [shareholders]*" (Companies Act 2013, s172).

The WWF and the Canary Wharf Group have both acted as construction clients. Their differing missions (after Mazzucato, 2016) and purposes, objectives and value drivers – expressed as construction performance objectives relating to particular decision variables – are reflected in the decisions made (Spencer and Winch, 2002) and ultimately, the final built form. The nature of these value drivers will vary from client to client and project to project, and may be extended by the consideration of the value concerns of a wider group of internal and external stakeholders (Storvang and Clarke, 2014). Construction clients will typically be interested in a set of decision variables that

support their conceptions of value. This client related sub-set of variables is described here as ‘client variables’. These variables and the associated performance objectives further refine a decision’s solution space altering the limits of a DMU’s agency.

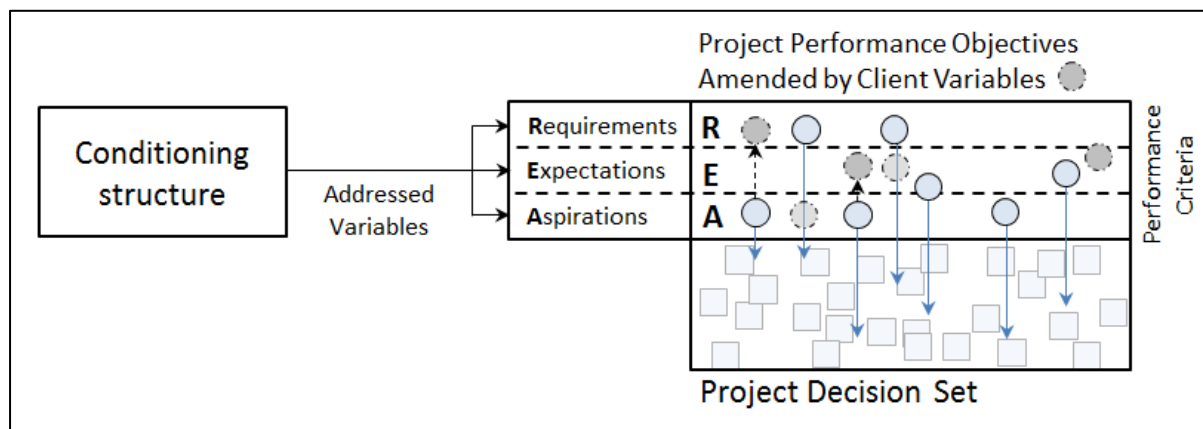


Figure 21 – Client performance objectives overlaid onto contextual objectives

Figure 21 shows how client variables and the associated performance objectives might influence a DMU’s solution space by altering the performance objectives for a project decision set. The left-most performance objective established following consideration of the context variables represents a contextual performance aspiration. This means that if the delivery of that performance conflicts with other client performance objectives, for example the pursuit of profit, the contextual performance objective may (perhaps carefully) be ignored without the fear of sanction. However, Figure 21 shows that the delivery of this particular project performance objective is considered to be essential for the successful delivery of value from the project for the client. While both context and client are concerned with the decision variable in question, the client considers meeting their objectives relating to that variable as a performance requirement. For example, a company may establish a project-level objective to create a demountable building capable of re-use. This would become a performance requirement for the project notwithstanding it represents an aspiration in the wider context as a response to resource depletion. Where clients place a less arduous performance objective on a decision variable than the context, the contextual requirements within which the client operates will prevail in shaping the decision’s solution space. That is, unless the client wishes to risk sanction for using an illegal or inappropriate solution. To generalise, if two sources of performance constraint are considered as a hierarchy, the lower level of the hierarchy may choose to impose stricter performance objectives or more challenging constraints, but in the face of sanction for transgression, may not deliver weaker performance objectives or constraints. The new client performance objective (expectation) to the far right of Figure 21 indicates that clients can introduce variables and performance objectives for consideration in project decisions that are not addressed by context factors.

In much the same way that the context variables and performance objectives for projects guide the establishment and actions of organisations, these client variables will influence decisions to be made in the construction project. For example, in the brief for their new head office, opened in 2013, the

WWF called for (required) an exemplary sustainable building. This abstract requirement for a 'sustainable building' was eventually made sufficiently granular and led to a focus on embodied GHG. Including a performance requirement relating to embodied GHG resulted in a 42% reduction from the planning baseline (Gerrard et al., 2015).

Indeed, due to their position in the project hierarchy, clients are considered to have significant influence over NMS specification and implementation in a construction project. Giesekam et al. (2015) found that client requirements were the second most cited reason for the selection of 'low impact materials' on projects. When considering the future importance of the role of the client in encouraging the use of alternative materials and construction products, 'more environmentally conscious clients' ranked equal first with regulation as 'extremely important'. This indicates the similarity of the pressures brought to bear on the specification decision by context and client variables. However, WBCSD (2012) found "*little evidence to suggest that clients are seeking specific material outcomes based on material sustainability criteria at this time.*" While this appears to be slowly changing, the rate of change seems to be insufficient to deliver the necessary reductions in embodied GHG on projects (Steele, Hurst and Giesekam, 2015).

#### *DMU Variables*

The solution spaces for the decisions to bring a project to completion are, therefore, shaped by project performance objectives arising from both client and context, addressing a subset of the universal set of decision variables. However, there still remain a large number of variables in the universal set that an individual decision-maker (or DMU) might consider important, for example, the impact of a mineral extraction process on the habitat of the pygmy three-toed sloth. While such a specific attribute is unlikely to be an explicit decision variable at a client or project level, it may be considered of vital importance to the individual. The additional decision variables considered by an individual or DMU as important, influenced by the DMU's endowments and value concerns (after Fellows and Liu, 2018), are termed '*DMU variables*'.

If the DMU's variables and associated performance objectives are not adequately addressed by the context and client, they may choose to incorporate new variables or more challenging performance objectives into their decision-making, further restricting their decision solution space. However, the DMU sits at the base of the decision hierarchy, influenced by both context and client. As such, where the outcome of their decisions conflict with the performance objectives of the context or client, that is, the structure conditioning their decisions, the DMU's preferences may be overridden, or they may be sanctioned.

Giesekam et al. (2015) found that personal motivations were the key reason that his survey respondents selected 'low impact materials' for projects, echoing the findings of Persson and Grönkvist (2015) in the context of the Swedish housing market. Similarly, in a survey reported in Jones et al. (2016, Appendix F), 30% of the proposals for the use of cross-laminated timber on projects were not in response to client requirements. Together, these suggest that the DMU



motivations, reflected in their performance objectives, can play a significant part in NMS specification on construction projects.

#### *PBO Variables*

The unlucky individual tasked with bringing the project to completion must explore and resolve each of the necessary decisions to define the full set of performance attributes for the project. However, understanding the performance constraints and objectives for the entirety of a project requires knowledge of many domains. While the DMU might be competent to make suitable decisions in some of these areas, many will fall outside of their competency (Reve and Levitt, 1984; Winch, 1989). The individual and organisation has a limited endowment of resources: such as knowledge, time, and experience limiting their capacity and competence to make informed decisions.

The DMU, perhaps unconsciously, assesses the time and cost implications of developing their competence to address these decisions and compares it to the time and cost implications of outsourcing the task of exploring and resolving certain subsets of the project decision set. This is the point at which transaction costs (Section 7.8) determine what is efficient for the decision-maker to pass to other organisations, and which decisions they should reserve for themselves. Those decisions from the project decision set that they wish to reserve form the client's 'decision set', those that are passed to a PBO to explore, make up the relevant PBO's decision set.

The volume of decisions reserved by a client has been observed to be broadly in proportion to the frequency in which the client builds (Mackinder, 1980). The question as to which decisions are reserved is, therefore, contingent (Sexton, Abbott and Lu, 2009). For example, a repeat construction client, such as a property developer, is likely to have the physical and cultural endowments to make more of the necessary decisions than would a first time client, and so is likely to reserve relatively more decisions. Some clients seek to retain control over the specification of the majority of the elements of their building, as happens with supermarkets, for example. However, such extensive control over specification is rare, and clients typically choose to specify limited elements which are very important to them, preferring to specify performance at varying degrees of abstraction, leaving room for interpretation by others. A director of a consultancy firm explained how being overly specific in construction specification leaves little room for contractors to innovate, or make a profit on projects, reducing the incentives to take on work. This often results in formal specifications being caveated with 'or equal approved', providing the contractor with some degree of latitude in the final selection of materials, and the opportunity to avoid NMS implementation (*"That's where the problem lies"*, Interview 1).

The task of describing and exploring the solution spaces for project decisions, and consideration of the solutions available to the project for each decision is therefore typically allocated – through a contract with a tightly defined scope of services – to specialist PBOs: consultants; contractors; or sub-contractors. The specific roles of each, however, are entirely dependent on the procurement route and contractual arrangements selected by the client – an early decision often taken on the basis of

recommendation of the client's advisors. In this way, PBOs bring their endowments of experience and knowledge to the exploration of the solution space.

One notable example of decision allocation observed several times occurs when a client effectively delegates decision-making authority to one of the PBOs for a decision, without recourse. For example,

- a client called for a landmark building, and entrusted the definition and delivery of that vision to the architect (Interview 5).
- an inexperienced (private) client employed an architect to deliver their building as they saw fit, having described their broad performance aspirations (Interview II).

Another time this might occur is through the use of the Design and Build procurement route in which a performance-based specification is passed to a contractor for delivery (Sexton and Barrett, 2005). In such circumstances, decisions taken by the PBO can have the weight of a project decision, elevating the PBO in the project hierarchy (Figure 22). Such delegation requires great trust in the relevant PBO.

The various PBOs to whom decisions are allocated (or delegated) are not unbiased in their decision-making. They may choose to incorporate additional variables from the universal set into their decision-making process. While these variables may not be addressed by context or client performance objectives, they will constrain the decisions the PBO / DMU makes (Bell, 1994; Male et al., 2007). These *PBO variables* will influence the exploration and resolution of decisions on behalf on the client by further restricting the DMU's solution space. For example, an architect might be concerned to deliver an award-worthy building, which may not be considered important in the context or client performance objectives. As individuals working in a PBO are tasked with exploring the possible solutions for a particular aspect of a building project, they will also consider their own DMU variables in the decision.

A further concern within organisations is how the agency of individuals is influenced by the organisational structure within which they operate. Simon (1957) describes how decision-making hierarchies are established in the Fordist production model, with limits to the agency of each individual carefully managed. In this way, those at the lowest levels of the organisation hierarchy have very limited agency over their work. In a production line, for example, operatives repeat tasks with little deviation. Where there are exceptions, these will be referred to the supervisory or managerial levels of the hierarchy. In turn, these managers refer to their superiors when the limits of their approved agency are breached. This escalation continues to the top of the organisational hierarchy, the senior management of the company. These actors operate with significant agency, moderated by their own decision variables, the context variables within which they operate, and the variables of interest to an organisation's stakeholder group. Decisions made at the senior management level direct and influence those below them in the hierarchy. If a worker exercises

agency beyond their scope that conflicts with the requirements or expectations of their senior management, the decision is likely to be moderated, or sanctioned.

### *Unconsidered Variables*

After incorporating context, client, PBO and DMU variables and the associated constraints into the decision-making process, there remains a vast number of variables that are not considered by anyone on the project team for a particular decision. The process of lock-in and the institutionalisation of processes typically preclude consideration of many of these *unconsidered variables*. Embodied GHG has typically been one such variable. The attempts to influence decision-making through communication, education and training described by Chan et al. (2017), discussed in Section 6.3.2, each aim, in part, to move decision variables from the set of unconsidered variables to one of the other four categories of variable. For example, industry communications conveying the importance of sustainable technologies can be seen as encouraging individuals, PBOs, or clients to define and promote performance objectives relevant to these decision variables.

These variables may be unconsidered because they are simply too remote from the project to occur to any of the project participants, for example the habitat of the three-toed sloth. However, there is a sub-category of such unconsidered variables that remain unconsidered due to their potential to cause conflict with dominant powers in the construction project. This leads to what Bachrach and Baratz (1963) describe as ‘nondecision-making’. That is,

*“The practice of limiting the scope of actual decision-making to ‘safe’ issues by manipulating the dominant community values, myths, and political institutions and procedures”.*

*Bachrach and Baratz, 1963*

These limits of scope need not be formally or consciously articulated in a project context, but are exercised as a form of self-restraint by the decision-maker when faced with more powerful authority, such as an employer, contractor or even a dominant economic ideology.

Bachrach and Baratz (1963) describe how this exercise of power occurs when:

- the DMU threatened with a sanction is aware of what is expected of him;
- the sanction is regarded as a deprivation;
- the person threatened values the sacrifice from sanction greater than the value foregone from complying; and
- the threat is considered to not be idle.

In such a situation a DMU (or indeed PBO or client) may *want* to specify an NMS on a project, but recognising that the potential sanction for doing so might be the loss of employment, status, or future income streams, they choose to forego their own performance objectives. Such rational inattention is a typical manifestation of the lock-in described in Jones et al. (2016), and mirrors the individual level decision-making dynamics that lead to ‘The Tragedy of the Commons’ (Section 1.2). As Ophuls notes *“... to bring about the tragedy of the commons it is not necessary that men be bad, only that they not*

be actively good ...” (Ophuls, 1977). This self-sacrifice is also addressed by Archer (1995) in the context of the need for analytical dualism in the exploration of structure and agency:

*“... since conditioning is not determinism, the [interaction] element of the [morphogenetic] cycle also recognizes the promotive creativity of interest groups and incorporates their capacity for innovative responses in the face of contextual constraints. Equally, it accommodates the possibility of reflective self-sacrifice of inherited vested interests on the part of individuals or groups.”*

Archer, 1995

### **8.3.3 The Decision Context as Hierarchy of Constraining Variables**

These sources of variables defining a DMU’s solution space are echoed in those uncovered in recent abductive grounded theory research on decision making relating to early contractor involvement on projects (Rahmani and Leifels, 2018). Rahmani and Leifels identify project characteristics, client objectives and the internal and external environment as influencing the selection criteria. However, their analysis remains limited for the purposes of this study as they conflate PBOs and individuals under the heading of “*Internal [project] environments*”, precluding the opportunity to study the individual’s exercise of agency. Further, they omit any consideration of hierarchy, and the emergence of the decision defining selection criteria.

Figure 22 partially addresses these shortcomings by presenting the decision context as a project hierarchy reflecting the typical authority levels and associated ability to sanction on projects. Emergence will be discussed further below. Performance constraints and objectives at higher levels in the hierarchy influence entities at a lower level (Sorrell, 2018), with performance objectives at higher levels having a broader influence on decision-making than those at lower levels, i.e. across more projects. This influence results from having a greater stock of ‘authoritative resources’ (Giddens, 1984) at the point of decision, or the ability to sanction lower order decision-makers. For example, context variables governed by national laws can apply to all actors in the industry in a country, and all potential projects, while the variables of concern to the DMU might only influence their own decision-making. Indeed, if the DMU’s performance objectives conflict with those of the PBO, client, or context, they can – and probably will – be ignored as and when the decision is passed on for validation or acceptance.

This hierarchical structure suggests that the efficacy of interventions in overcoming material lock-in is dependent upon the level at which the intervention influences the DMU’s solution space. For example, encouraging the consideration of low embodied GHG materials as a client performance requirement is more effective in ensuring implementation than by encouraging PBOs to aspire to specifying them, or providing information to a specifier to influence the likelihood of influencing their DMU variables. This is because – without economies of scale, and in the presence of transaction costs – the cost of using low embodied GHG materials is presumed to conflict with client budgetary expectations (Appendix 1), which, in the case of listed companies are conditioned by the market

expectations of rates of return (Jones et al., 2016, proto-theory 2). Interventions addressing lower level decision variables are typically more straightforward to implement and less time and cost consuming than those at higher levels, however, the narrow focus of intervention limits the breadth of impact.

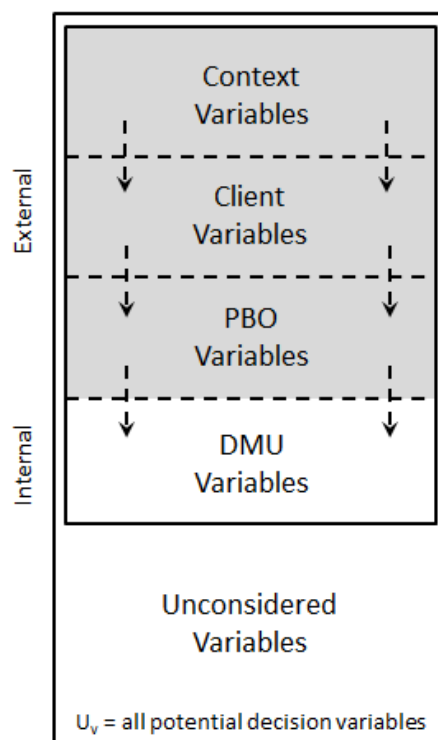


Figure 22 – The project hierarchy of decision variables<sup>9</sup>

It is important to note that each of these levels can influence the others: construction clients and PBOs can influence the context; a client’s brief is not developed in isolation, but typically in conjunction with the architect and other advisors. Indeed, Interview II described the importance of engaging with the client during brief development to encourage the client to adopt a PBO’s performance objectives. Similarly, Interview 3 discussed the importance of getting “*the client emotionally invested in the project...*”. While so invested, the client might also adopt the decision variables, performance constraints and, to an extent, the performance objectives of the PBO that have driven their specification decisions. As an example of this influence, one senior structural engineer commented that they were often unable to implement the innovations that they wanted to on projects because:

*“[We] just can’t get to the client to influence the decision. ... the relationship sits with the architect or contractor”.*

*Associate Director, Structural engineer*

<sup>9</sup> Supply chains have been omitted from Figure 22 for clarity. The tiered nature of supply chains will also influence decision-making at the PBO or individual level.

Or:

*“The proposal doesn’t even get to the contractor, [...] the client rejects them with the QS backing them up”.*

*Interview 2*

#### **8.4 Interaction: The Allocation and Making of Specification Decisions**

*“Remember, the client has delegated their value judgements to us.”*

*Interview 5*

It is, of course, quite typical for client organisations to employ specialist external organisations to review and interpret the context and client variables in relation to aspects of a construction project. Indeed, over time, as the complexity of the built product has increased, so too has the degree of specialisation and fragmentation in the construction sector leading to large numbers of organisations with discrete expertise (Brandon, 2006). The decisions allocated to a particular PBO for exploration will be controlled by a tightly defined scope of works and governed by a contract reflecting the procurement route selected, influencing their decision horizons (Section 7.11.2) (*“It holds us back”*, data point 9). In particular, the decisions allocated to a PBO will relate to the consideration of the context variables and performance objectives that influence their decision set, for example, fire and acoustic performances. This is often achieved by incorporating these requirements in the contractual relationship (discussed in Interview 7).

Figure 23 explores the interaction between these PBOs and the client, with the left hand side showing how decision sets of both client and PBOs are conditioned by the contextual contingent performance objectives. The DMU’s solution space is further structured by the introduction of client and PBO performance objectives, influencing the DMU’s agency in the selection of a solution for each of the decisions in their decision set.

The DMU in PBO<sub>1</sub> responds to the client’s aspiration for a building by identifying a preferred solution from their constrained solution space addressing the performance objectives of the context, client and PBO, as well as their own. The selection process may be one of satisficing, or may be a more formal decision-making process as described in Section 6.3.7 to improve the rigour and transparency of the decision-making. Having begun to define the detailed performance attributes of the final building, the delivery of the selected materials are considered as a new (emergent) performance expectation by the PBO (not shown) and subsequently, the client. For example, a context performance requirement may be that the building must resist wind loads. To meet this performance requirement, and the client’s performance aspiration for a building, the engineer proposes the project be completed in concrete.

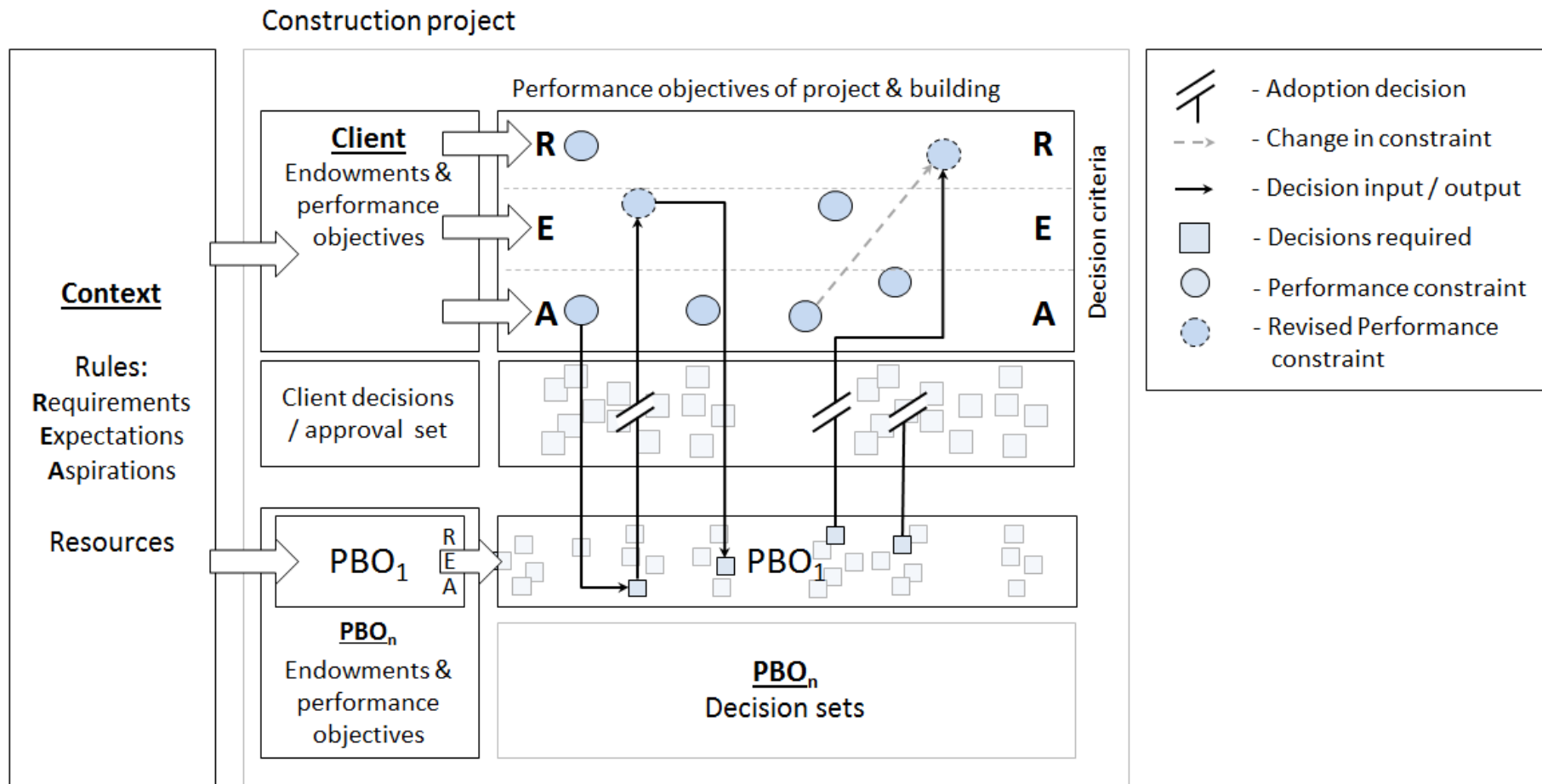


Figure 23 – Client adoption of PBO performance objectives

In this simple illustration, the PBO has taken a single abstracted performance requirement that can be met by a number of solutions and recommended a particular (satisficing) path, based on a review of their solution space for that decision. In practice, each decision will be influenced by a range of performance objectives each limiting the decision-maker's solution space. In the example, it is not a requirement that the project be completed in concrete, but it becomes a project performance expectation, and work proceeds on that basis. The creation of a new expectation does not eliminate the performance requirements that influence the decision - the building must still resist wind loads.

## **8.5 Elaboration: A Decision's (Immediate) Afterlife**

### **8.5.1 *Confirming PBO Decisions***

A project decision will typically have an elaborating impact on the conditioning structure for subsequent project decisions for both the decision-maker (for example through the opportunity cost of the decision) and other project actors (Archer, 1969). However, in the multi-party, multi-level construction project environment, this elaboration does not necessarily follow directly from a decision. A DMU's decisions are typically considered to be provisional and subject to review within the PBO (Section 8.5.2 below), by other PBOs (Section 8.5.3), before being accepted by the client into the project performance objectives (Section 8.5.4).

The order of this review process has import as the client may accept the proposed decision as a performance objective prior to other PBOs having a chance to consider the elaborating impacts on their performance objectives. This review process, identified by the broken line in Figure 23, tests the potential impacts of the provisional decision against the performance objectives of the impacted PBOs. Once decisions have been adopted by the client as project performance objectives – explicitly or implicitly – and communicated, they will constrain subsequent project decisions.

Recalling that different PBOs have different decision horizons, scopes of work, and conceptions of value, this process of decision moderation or sanction can be highly influential in the ultimate specification of NMS on a construction project. Clearly, if a provisional decision outcome risks the delivery of a project performance requirement for the building (e.g. it doesn't meet building codes) or delivery process (e.g. it will miss a launch date), the provisional decision outcome is likely to be rejected by the actor responsible for meeting that performance requirement. The project's decision conditioning structure will remain unchanged. Where aspirations are at risk of being unfulfilled, there may be resistance to the provisional decision, but the risk of the provisional decision being overruled is reduced.

However, performance objectives emerge and evolve over the course of the project, rather than being one-time declarations. The impact of a provisional decision outcome on a PBO's performance objectives for a project will, therefore, vary depending upon the timing of both the decision and the establishment of the coordinating PBO/DMU's performance objects. This emergent nature is discussed further in Section 8.6 below.



### **8.5.2 Validation within a PBO**

Validation occurs within PBOs through a process of review. The extent of the review within a PBO will be influenced by the quality assurance processes put in place, which in turn influences the scope of and limits of the DMU's autonomy and authority to act (after Simon, 1957). The extent of review will be influenced by the perceived endowments of the DMU in knowledge and experience, and their position in the organisation's hierarchy. For example, if a senior architect were to make a design decision, it would likely be subject to a significantly lower level of review than that of an architectural student on a placement. A reviewer will apply their understanding of the client, context, and PBO performance objectives to ensure that the conclusions reached by the DMU are appropriate, potentially allowing their own performance objectives to determine suitability.

In this way, smaller, privately owned creative companies might be considered more likely to propose novel solutions to construction projects. This results from an easier communication and coordination of the PBO's variables among DMUs in smaller organisations, fewer levels of authority between the DMU and the primary organisational stakeholder, and the reduced influence of external PBO stakeholders. A DMU's cost-focused decision would be less likely to be moderated by an organisational hierarchy that incorporates, or places additional weight on, commercial, rather than sustainable or design led outcomes. If the DMU's decision does not conflict with the PBO or reviewer performance objectives, then the DMU's performance objectives, perhaps reflecting their personal notions of value and performance objectives, will be incorporated into the proposals to address design issues on the project.

### **8.5.3 Acceptance by Other PBOs – Project Coordination**

Building on the earlier work of Thompson (1967) on organisation design and Rogers' (1995) exploration of the innovation adoption decision, Sheffer and Levitt (2010) describe how the implementation of the innovation (NMS) specification decision is not as straightforward as typically presented in the literature. This is particularly so in the multi-party construction context where there are significant interdependencies between organisations. Thompson (1967) describes three forms of interdependence: pooled, sequential and reciprocal. Pooled interdependence exists where each part of an organisation contributes to the success of the whole, but has limited influence on or connection to the other parts. Sequential interdependence arises when the output of one part, forms the input to another. Finally, reciprocal interdependence is the situation where the "*outputs of each become inputs for the others*", that is, "*the output of [...] groups must be negotiated to address sub-goal conflict*" (Taylor and Levitt, 2004). Complex organisation structures such as the construction project are typified by these reciprocal interdependencies, while also exhibiting degrees of sequential and pooled interdependence. While Thompson's work looked at individual organisations, the analysis has been extended to construction project contexts by Taylor and Levitt (2004) and Sheffer and Levitt (2010) among others.

It is this reciprocal interdependence that requires decision outcomes from one PBO to be negotiated, coordinated and accepted by the other PBOs involved in the project *at that point in time*. Such coordination places a heavy communication and decision-making burden on the project to ensure the transmission of new information during the process of project development, and a mutual adjustment of PBOs' positions to reach an agreed path forwards. The more uncertain and unpredictable the situation, the greater the coordination costs will be (Thompson, 1967). From a project efficiency perspective then, it makes sense to reduce these coordination costs by anticipating the performance objectives of other PBOs, and implementing solutions that lie within their common experiences and performance objectives.

*“But even before we propose [ideas] to the client, we’ll run them past consultants to see if it’s actually going to work. [...] there’s no point in presenting something to the client that doesn’t work financially, acoustically or all those various other things that you have to think about.”*

*Interview V*

The PBOs potentially impacted by a provisional decision will assess whether the decision might impact negatively on their performance objectives for either the project delivery or deliverable. Where the provisional decision threatens the delivery of the context, client or PBO requirements over which the PBO has oversight (e.g. fire safety, or structural integrity), barriers will be presented by the relevant PBO, requiring a reconsideration of the prospective decision by the originating PBO. In data point 9 one of the participants presented a slide (Figure 24) that demonstrated the tension arising from differing PBO performance objectives on innovation.

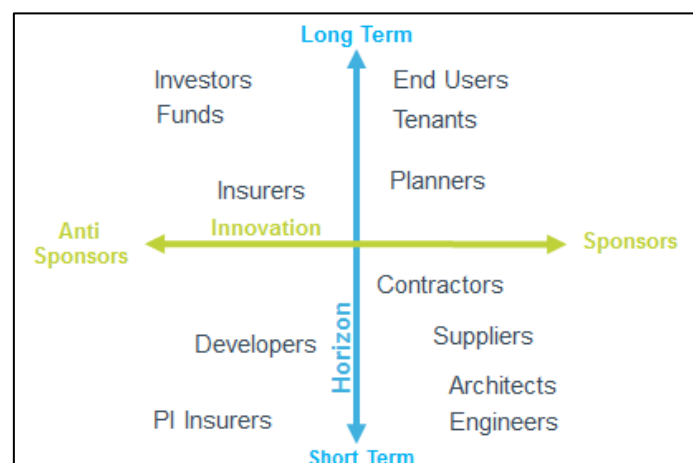


Figure 24 – Typical influence of stakeholders on innovation (data point 9)

This social interaction process is described by Archer (1995a): “*groups experiencing [potential losses] seek to eradicate them (thus pursuing structural change) and those experiencing rewards try to retain them (thus defending structural stability)*”. Where there is a conflict of objectives between PBOs, clients will typically be asked to make a decision, informing the trade-off between PBO performance objectives.

#### **8.5.4 Project Performance Objectives: Adoption by the Client**

A PBO's provisional decisions will normally be presented to the client for adoption, possibly as part of a range of options. The client, or their designated representative, will assess the performance attributes of the solutions against the client's articulated performance objectives before accepting or rejecting each proposal as suitable for the project performance objectives. By adopting the decision, and associated performance objectives, the client is implicitly accepting the DMU and PBO's additional decision variables into the project, as well as the implicit assumptions that have gone into making that decision. Fellows (2014) discusses how such assumptions play a key part in projects, and that they are rarely explored. This thesis argues that for the successful specification of NMS in construction, these implicit assumptions should be explored more fully.

However, while the client may implicitly adopt the performance attributes incorporated into a decision outcome as project performance objectives, they may judge that the decision should carry a less stringent performance objective than the specifying PBO has proposed, for example, as expectation or aspiration, rather than requirement. The performance objective that a client assigns, or is presumed to assign, to a given performance constraint will then influence subsequent project decisions. For example, the client may expect, but not require, that CLT is used in the project. Alternatively, a client may adopt a recommendation as a performance requirement, convinced of the importance of the attributes, or willing to trust the judgment of their advisors. Indeed, in discussion, one structural engineer said that they were rarely challenged on their decisions for structural frames.

In the experience of the researcher, architects are frequently challenged about their design decisions. It is hypothesised that this is because many of the decisions taken by structural engineers are governed by context and project requirements for stability, safety etc., and face a relatively limited range of potential solutions in their solution spaces. Architects, however, are faced with a large number of potential solutions in their solution spaces that will meet the project's functional performance objectives defined by the client and context. That is, the solution space for a given architectural decision is more densely populated than those for structural engineers. The appointment of a powerful contractor (after Chang and Ive, 2007) means that new performance objectives may be brought to bear on the architect's solution space, eliminating the previously selected provisional specification. Unless the architect's recommendation has previously been accepted as a performance requirement by the client, there is a risk that their performance objectives will be overridden. This was a strategy adopted by one interviewee (interview II) in the CLT study to ensure that CLT was not removed once the contractor had been appointed (Section 5.3.3).

### **8.6 The Morphogenesis of Project Structure: Introducing the Consideration of Time**

#### **8.6.1 In the Beginning, All is Agency**

The performance objectives imposed on a construction project by the different project actors and the processes of decision-making and coordination have so far been explored without consideration of time beyond the immediate aftermath of a decision. Moving from a project of entirely undefined

performances and the related array of unmade decisions (Section 8.2), to a fully specified building will involve decision-making over time. However, as the outputs from decisions in the construction project can constrain later ones (Archer, 1969), the sequencing of this decision-making is important. Opportunities for NMS specification can be created or eliminated by early project decisions.

Prior to a project's establishment at  $t_1$ , no performance objectives or governance structure exists. All is agency. Starting from this position of maximum uncertainty over the required performances of the construction process and product, decisions are made that will, over time, define a complete and unique set of project performance objectives. Each decision informing these governance structures and performance objectives is taken through an exploration of a DMU's solution space, shaped by the conditioning structure *at the point of decision* that restricts the exercise of agency. The following sections explore the impact of introducing a consideration of time to the model developed thus far (Figure 23). Section 8.6.2 discusses the importance of the sequencing on the evolutionary development of a decision's conditioning structure. Section 8.6.3 then explores how PBO commitments of cultural and resource endowments can change over the course of the project, further influencing a decision's conditioning structure.

## **8.6.2 The Influence of Emergence on Performance Objectives**

*"Valuers and agents are looking backwards, not forwards..."*

*Speaker, data point AZ*

### **8.6.2.1 The Establishing Decision – Underlying Assumptions**

Context and broader client performance objectives shape the decision, taken at  $t_0$ , to establish a building project. By adopting (or indeed, rejecting) these performance objectives in the establishing decision, the morphogenetic elaboration of the project performance objectives, and hence the conditioning structure of decisions, begins. At this moment of establishment, uncertainty over the final project performance attributes is at its peak. Accordingly, the establishing decision will need to be supported by a vast number of simplifying assumptions and estimates about the client's performance objectives. Box 1, below, explores the implications of one such set of assumptions relating to cost. To the extent that these have been articulated at all, they are likely to be expressed in terms of aspirations, rather than expectations or requirements. However, many of the earliest project decisions following project initiation relate not to the detailed performance objectives of the building-to-be, but, significantly, to the process of delivery of the - as yet unspecified - performances.

**Box 1: Building on Assumptions – Cost Estimates**

In the face of significant uncertainty, initial project costs estimates are typically made by looking at the cost of similar completed buildings – offices, museums, factories – based on a common functional unit, typically cost/m<sup>2</sup>. The abstraction adopted here clearly ignores the context specificity and bespoke nature of the project at hand. Therefore, initial project budgets will be informed by *historical* cost precedents, moderated by a DMU's experience, or by reference to the Royal Institute of Chartered Surveyors' (RICS) Building Cost Information Service (BCIS). This historic cost data can be flexed to enhance the applicability of the data to the current context. There will, however, be no perfectly representative reference building.

By adopting these historic costs as the basis for the development of project cost estimates (or time, data points P, AR), the DMU implicitly assumes that the performance attributes of the construction solutions adopted in these reference projects will be implemented in the new project. These prior construction projects may not include NMS. Certainly, these assumptions can be flexed for known specification differences and performance objectives articulated when the budget is set. However, at the project's inception, few detailed performance objectives will have been established. At the point when the business case is established and formalised into organisational planning (see below), the opportunity to incorporate performance objectives relating to non-client decision variables can already be settled.

As the project proceeds, certainty over the eventual project performance objectives and material specifications increases. The abstraction of the cost model is then reduced by the development of an elemental costing plan. However, the outcome of this 'bottom up' costing exercise will be compared to the project expectations established by the early estimates. Negative variances between these early estimates and the elemental cost is generally eliminated through a process of value engineering, or the use of contingency.

This process of elemental costing is itself supported by a set of assumptions about construction methods, market rates and competitive pricing, gleaned from other locked-in, competitively tendered projects, and industry cost models. The construction methods used to establish these cost models will then be implicitly adopted into the new project. Once this value engineered, elemental cost plan has been accepted through the relevant project gateways, revised cost expectations are established over particular building elements.

**Box 1 / Cont..**

As the Quantity Surveyor (QS) is entrusted with managing the delivery of the project to budget (performance expectation), they will be keen to ensure that these elemental budgets are not exceeded, failure to do so may lead to sanction. This again mitigates against NMS implementation in construction projects as – at this elemental level – they are likely to be or be considered to be, due to the associated transaction costs (Section 7.8) more expensive than the dominant market solutions. Indeed, exploring the adoption of cross-laminated timber (CLT) during phase one of the research the research found repeated instances where CLT had been rejected from projects because it breached this elemental cost expectation, notwithstanding the other project benefits that it delivered. Jones (2014) reported how the QS was viewed as presenting more high levels of resistance to the use of CLT than any other source. This is an example of a circumstance in which the contracted responsibilities of the QS has reduced their decision horizons to such an extent that they do not consider matters beyond their narrow field.

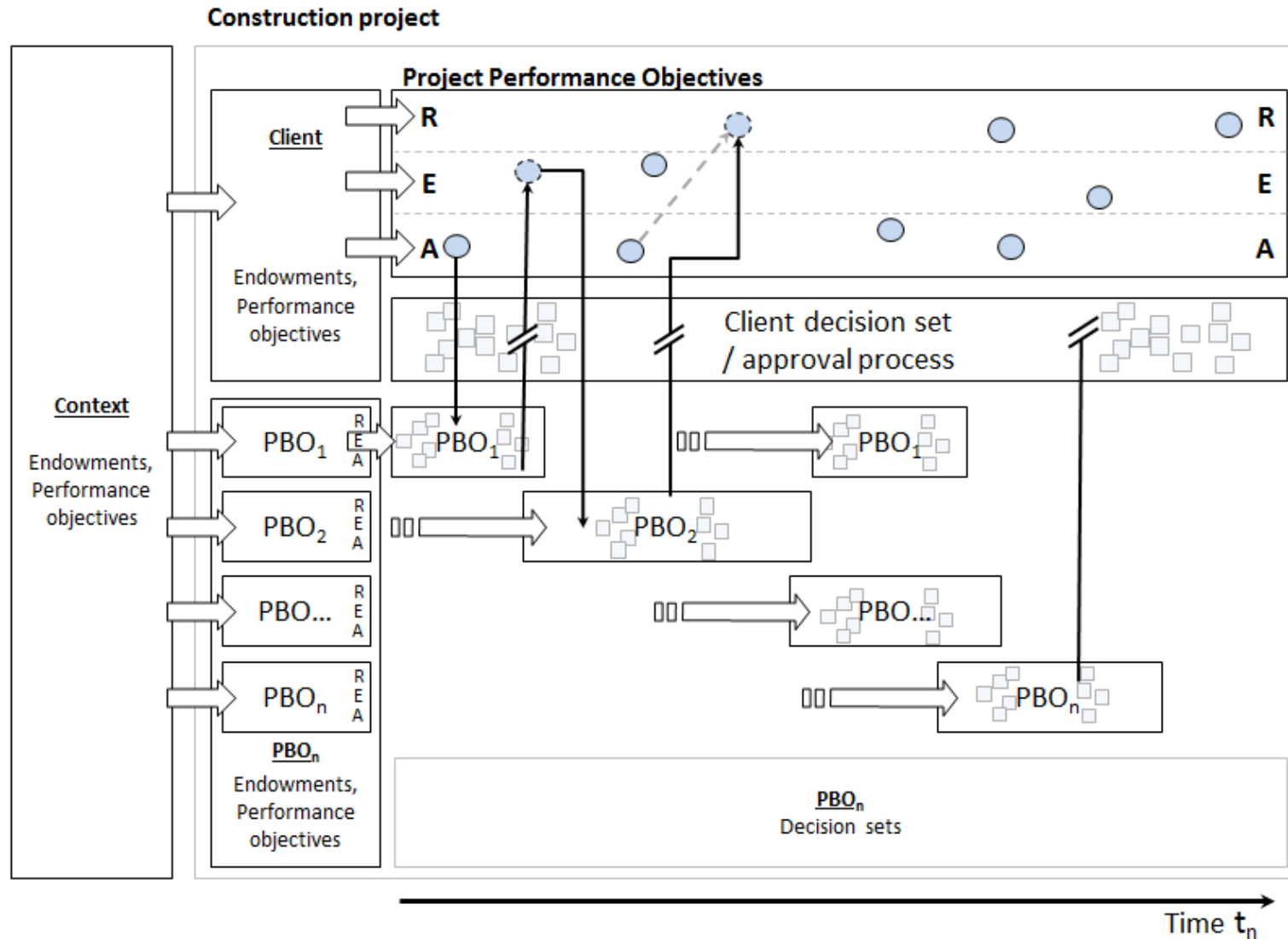


Figure 25 – The dynamic, emergent, model of the construction project as decision array

### 8.6.2.2 The Emergence of Project Aspirations and Expectations

#### *The Sequencing of Appointments and Decisions*

Completing the middle-range model of the construction project as decision array, Figure 25 explores the influence of emergence on project decisions through a consideration of the sequencing of decision-making and PBO appointments. In Figure 25 a client identifies an aspiration for a building. (after Spencer and Winch, 2002). Their decision to initiate a project to address this aspiration is informed by the opportunities and threats in the context in which the company operates (Appendix A), their wider performance objectives and cultural and resource endowments. To address project uncertainty, a number of assumptions are made in this initiating decision. Together, the conditioning structure of this decision and the early assumptions shaping it inform the project decisions that follow. Subsequently, PBO<sub>1</sub> is appointed and entrusted with an exploration of a subset of project decisions, their decision set. The solution space for their decisions are informed by the conditioning structure created by the context and the client's initiating decision, coupled with their own performance objectives, endowments and assumptions (PBO Performance objectives), influenced by their decision horizons (data point 9).

Once resolved, a PBO<sub>1</sub> decision may be adopted by the client and becomes (in this example) a project performance expectation – for example, PBO<sub>1</sub> might have provided a completion date that the client decides cannot be missed. To be clear, this adoption can be explicit or implicit. PBO<sub>2</sub> subsequently joins the project and must now consider these adopted (PBO<sub>1</sub>) decisions as being client performance expectations, rather than simply those of another PBO.

If the PBO<sub>1</sub> decision had led to a client aspiration (for a sustainable building, for example), the associated performances could be considered to be less binding on PBO<sub>2</sub>'s solution space. In this manner, the sequencing of both appointments and decision-making can be seen to influence the conditioning structure of subsequent project decisions, and hence, the agency with which PBOs appointed later operate to deliver the required and expected project outcomes.

*“As different actors inhabit different positions in the system, they are affected differently by the structure, as some actions are enabled and some are constrained.”*

*Svensson and Nikoleris, 2018*

PBO<sub>2</sub> will then make decisions that can in turn influence the solution spaces for other PBOs (PBO<sub>n</sub>), or later decisions of PBO<sub>1</sub> binding subsequent decisions (data point P)

One other item of note in Figure 25 is the grey dotted line connecting a performance aspiration to a later performance requirement. This arrow indicates how, due to the passage of time (or associated activity) performance objectives that were once considered to be aspirations can transmute into performance expectations or requirements. This might arise if a client makes a firm decision on a design item that had previously been in abeyance, or indeed, if an earlier un-adopted decision has already been actioned and built, as has been observed in practice. Observations (data point D) show



that change will be resisted once an investment of resources has been committed to a particular path, or decisions have been made based on an earlier expression of performance aspirations or expectations. The resource endowments that PBOs have committed to the project are fixed in the short term (Section 8.6.3), and proposals to re-visit a PBO's work, once such a level of commitment has been reached, may risk breaching the PBO's financial performance expectations. Once project decisions set sanctionable performance requirements or expectations a project level morphostasis begins to set in.

### *The Institutionalisation of Decision Sequencing*

The continuing importance of meeting the client's performance expectations and requirements has led to the institutionalisation of the sequence of decision-making through instruments such as the RIBA Plan of Work (2013), the Building Services Handbook (Churcher and Sands, 2014) and the UK Government's OGC (Office of Government Commerce) Gateway Process (Cabinet Office, 2011). Each of these project delivery frameworks encourages project teams to establish the 'business case' for the project at the earliest opportunity. That is, to formalise the expectations of costs of, and strategic benefits from the project anticipated in the establishing decision.

Further, these instruments each recommend the use of project gateways, predetermined points at which reviews are undertaken of the cumulative project information and decisions. The aim is to ratify that project decision-making is delivering the performance objectives that were anticipated in the establishing decision (Egan, 2002; Smyth, 2016), as amended – through change control – during the development of the project. These project gateway reviews are typically endorsed by the project sponsors, key project stakeholders. Once approved, the performance requirements and expectations (together 'sanctionable performance objectives') contained in the gateway review documents can be incorporated into organisational planning and reporting. By formalising decisions, this gateway approval process can alter the status of performance objectives, for example from aspiration to expectation. Over time, and across gateway reviews, the cumulative decisions made over the performance objectives for the project describe an increasingly concrete and specific picture of the performance attributes for both the building and project, forming the conditioning structure for decisions that follow. This reduces the agency of those engaged at the end stages of a contract, such as some installation sub-contractors, to a minimum.

### **8.6.3      *Emergence, Expectations and PBO Willingness to Apply Endowments***

It was observed during the study that the attitudes of project participants to NMS implementation on projects varied over the life cycle of the project, and was influenced by the timing of the proposal. This section locates this observation in the context of the decision-based model of the construction project.

Each consultant or supplier to a project represents a discrete entity with their own goals and performance objectives beyond the project (Winch, 2014), committing a proportion (typically not all) of their (physical) endowments to the project (Figure 3 refers). That is, a distinction can be drawn

between the cultural and resource endowments that a PBO has, and those that it can, and will allocate to a particular project. At times, their roles as organisations and project participants can come into conflict (e.g., Hobday, 2000).

In learning of a project opportunity, a PBO might aspire to work on the project in pursuit of the organisation's wider performance objectives (cf. Bell, 1994). These goals may be economic, but can also reflect other means of value generation such as gaining pre-financial competitive advantages, experience, or marketing collateral (Interview VIII), learning about new materials (Interview VI), the use of otherwise redundant resources, and so on. Irrespective of the particular goals that a PBO pursues, their decision to engage with the project will be based on an assessment of how their engagement influences the attainment of these goals. That is, the PBO anticipates the project's contribution to their organisation, shaping the PBO's project performance objectives. Delivering on these project performance requirements, expectations and aspirations, are key to a PBO's decision-making.

PBOs are often willing to engage with clients before formal appointment to the project to discuss novel ideas with, or on behalf of, clients. This work may be performed under pre-delivery contracts, but more commonly it is undertaken speculatively, through charrettes, competitions, or provision of unpaid project advice, in the hope of winning future work. These activities represent speculative investment decisions on the part of the PBOs in pursuit of future value. Pre-contract, novel ideas can be explored without significant risk to the PBO's organisational performance objectives as they have committed to invest fixed and limited resources to assist the client.

Project performance objectives that are established prior to a PBO formally contracting to join the project team can influence the PBO's anticipation of the value achievable from a project. This in turn can influence their performance objectives, and the resources they may be willing to commit to the project. For example, an early decision to use straw bales in a project may lead to an increased need for learning or testing for a PBO, but may also provide significant marketing opportunities. It may also lead to the anticipation of additional transaction costs. The alignment of the value that can be obtained from the project with the value needs of the PBO will influence the PBO's willingness to commit resources to the project.

The left hand side of Figure 26 illustrates the pre-contract position in which a PBO can adjust their fees to cover these additional expected costs, or reduce fees and commitment as the circumstances dictate. The boundary between the organisation and project commitment remains fluid. At the point of contract, however, the PBO's project expectations and aspirations must be translated into the currency of transactions: a fee and associated scope must be agreed. The act of agreeing contracts fixes the level of commitments from the PBO to the project and establishes (PBO) sanctionable organisational expectations of value outcomes from the project (Figure 26, right hand side).

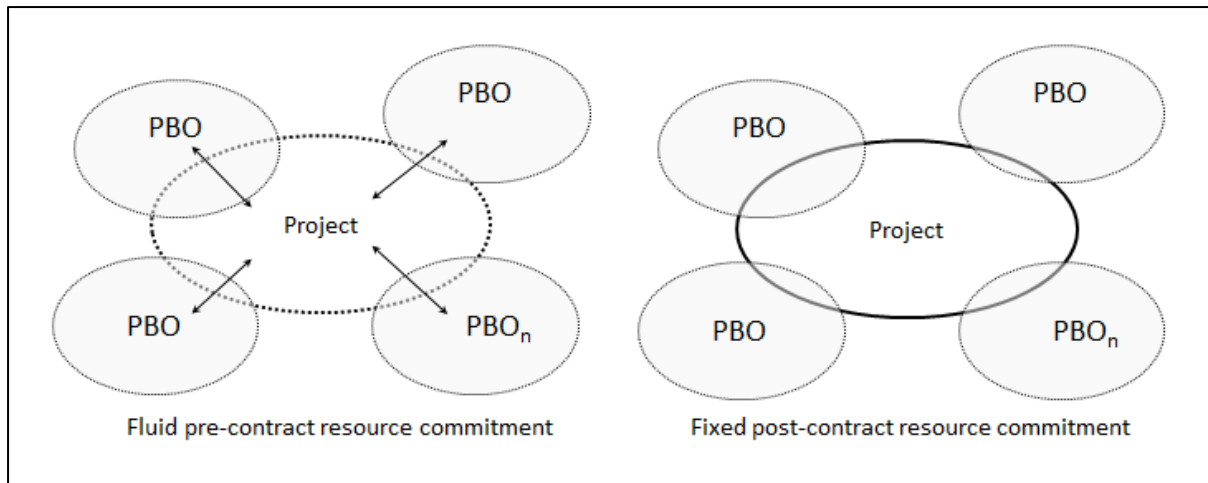


Figure 26 – Commitment of resources to a project pre- and post-contract

However, such contracts are typically struck in the face of significant uncertainty, which reduces as the project proceeds. The higher the uncertainty at the point of contract, the more akin to a gamble is the project commitment. The timing of the striking of contracts, therefore, has an impact on the uncertainty to which a PBO is exposed. Addressing this uncertainty requires an assessment of, or the making of assumptions about the likely course of the project, and the opportunity to mitigate the uncertainty, typically, through the appointment of sub-contractors. Each PBO will make its own assumptions about the work required on the project, influenced by their experience, work processes, value drivers and anticipation of transaction costs. The proposed fee, underpinned by these assumptions, places limits on the resources the PBO is willing to commit to a project, and to set their organisation's performance objectives relating to the project delivery process. Those PBOs anticipating or supporting NMS implementation on a project will, all else being equal, charge higher fees than those anticipating the use of dominant solutions.

The PBO's decision on pricing and scope will reflect, *inter alia*, the degree to which the PBO wants to win the work, their aspirations for the profitability of the project, their endowments of resources and experience, and the amount of residual uncertainty at the point of contract. The delivery of these profit expectations increases the importance of scope and delivery management for the PBO. The striking of contracts, therefore, alters certain PBO performance objectives from aspiration to expectation, re-structuring the DMU's solution space, and limiting the opportunity to accommodate additional work, or costs (Figure 26, right hand side, Figure 27). If provisional specification decisions call for additional project resources from the PBO, exceeding these expectations, the delivery of PBO performance objectives will be put at risk. Barriers will be presented.

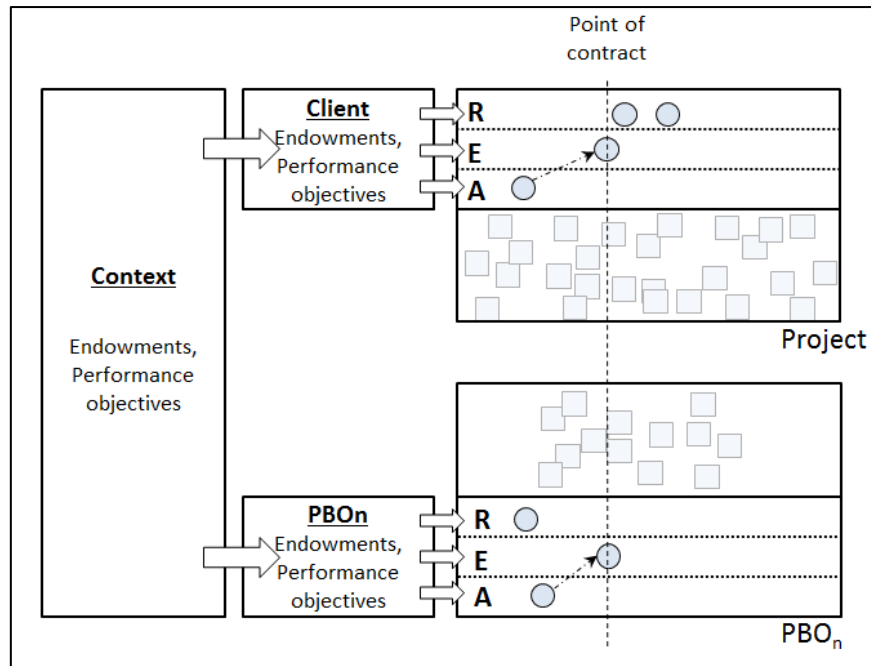


Figure 27 – The effect of contracts on performance aspirations

## 8.7 Model Validation

The hierarchical model of the decision context presented in Sections 8.3.2.3 and 8.3.3 above was presented for challenge at a Bartlett 2017 Doctoral Conference on Sustainable Built Environment (Appendix G). The concept was well received by attendees, including Professor Hedley Smyth of the Bartlett School of Construction Project Management who suggested incorporating the notion of non-decision-making into the analysis. Professor Peter Hansford, the UK Government's former chief construction adviser was also in attendance. Following the finalisation of the model, it was presented in its entirety for challenge in a session at the sponsoring office attended by structural engineers and sustainability consultants at various levels of seniority, including two attendees with doctoral qualifications. At this session, questions were raised, and addressed, but no significant changes were required to the theoretical model of the construction project. The model has also been presented to director and associate level project supervisors at the sponsoring organisation and academic supervisors throughout its development.

## 8.8 Conclusion

In pursuit of objective 2 of this thesis, this chapter has introduced a middle-range, decision-based descriptive model of the construction project, developed in line with methodology and methods described in Chapters 3 and 4. The model describes the construction project as an array of decisions to be made in the face of emergent performance objectives and commitments of endowments of various project actors, shaping decision solution spaces. It provides a context sensitive framework within which specification decisions can be located and interventions assessed, and has addressed three of the four characteristics required of a framework outlined in Chapter 6:

- It is dynamic and accounts for the emergence of structure in projects;

- Researchers can use it to locate the specification decision in the nested, hierarchical conditioning structure within which project decisions are taken;
- It is sufficiently flexible to cope with any potential project circumstance.

Adopting a morphogenetic view of the construction project allows the model to describe how the emergent nature of the assumptions and performance objectives in the construction project influences the opportunity to specify NMS on projects. This emergence calls for an exploration of the performance objectives and endowments shaping the DMU's solution space *at the point in time* at which the specification decision is to be made. The institutionalisation of assumptions and sequencing of decision-making in pursuit of project efficiency is identified as limiting the consideration of NMS on construction projects.

The next chapter synthesises the literature and empirical evidence gathered to address the final requirement of the framework by providing a means by which the impacts of interventions on the specification decision can be assessed.

#### Box 2 – The Influence of Sequencing Decisions

##### **Box 2 – The Influence of Timing: The Sequencing of Project Expectations**

The 1967 RIBA Plan of Works (RIBA, 1967) recommended that architects be appointed at the outset of the project (Stage A) making the architect one of the earliest appointments in a project, for example PBO<sub>1</sub> in Figure 25. Consideration of costs in the 1973 Plan of Works comes during the second stage (Stage B), for example, by PBO<sub>2</sub> in Figure 25. The decision as to which architect to appoint would be made on the basis of some form of client judgment, possibly personal recommendation, artistic, reputation, or cost. These selection criteria would, consequently, influence the proposed design expectations and therefore the resulting budget for the building, considered at Stage B.

Today, however, the business case is typically set at RIBA Stage 0 (Strategic Definition) before work commences on the design of the building at RIBA Stage 2 (Concept Design). Therefore, the design team will typically be required to work within a predefined budgetary envelope (Box 1) established before their full engagement on the design of the building, limiting their agency. In this context it is notable that BREEAM credits are available to construction projects for the early appointment of a BREEAM Accredited Professional who is tasked with establishing and guiding the delivery of project expectations for BREEAM scores (e.g. BRE, 2014).

Further, the appointment of sub-contractors typically occurs very late in the development process. This means that many decisions over performance expectations will have been confirmed before they get involved, limiting their agency to a minimum. If these sub-contractors attempt to overlook performance objectives established previously and structuring their solution space, their proposed specifications are unlikely to be acceptable for the project, illustrated on the right hand side of Figure 25.

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## 9 Assessing the Novel Material Solution (NMS) Specification Decision

*“No increase of expenditure over the unavoidable minimum is expedient or justifiable, however great the probable profits and value of an enterprise as a whole, unless the increase can with reasonable certainty be counted on to be, in itself, a profitable investment.”*

*Wellington, 1887*

### 9.1 Changing Construction Material Specification Behaviours

The process of lock-in described in Jones et al. (2016) incentivises construction organisations to continue to use the decision-making behaviours and assumptions adopted on previous projects in pursuit of competitive advantages (after Arrow, 1962):

*“...you want to make things repeatable, reduce risks, fix time scales, fix costs, fix overheads, and essentially do the same thing over and over again.”*

*Interview I*

This industry-level process of lock-in represents a form of morphostasis: dominant assumptions and practices are reinforced through institutionalisation and repetition. At the level of the individual project and specification decision, morphostasis is reflected in the planning of projects on the assumption of the use of dominant solutions to meet performance objectives (Chapter 8). Morphogenesis occurs at the project level when these assumptions are overturned, and an NMS is proposed from a DMU's solution space.

The first phase of the research (reported in Jones et al., 2016, Appendix F) explored the circumstances under which actors successfully challenged this locked-in / morphostatic specification behaviour, leading to the implementation of cross-laminated timber (CLT) on projects. The study applied the COM-B (Capability, Opportunity, Motivation – Behaviour) system of behavioural preconditions (Michie, van Stralen and West, 2011)<sup>10</sup> from the behavioural sciences to identify the importance of a DMU's motivations in overcoming material lock-in in the specification and implementation of CLT. Indeed, motivation is “... the main force through which individuals allocate effort to generate and implement innovative ideas” (Hartmann, 2006), being the automatic and reflective processes that direct behaviour (Michie, van Stralen and West, 2011). However, Jones et al. were relatively silent on the preconditions of opportunity and capability. Capability was presumed as being related solely to technical capability, while opportunity was considered to be presented by the existence of a construction project. The COM-B system analysis can now be located within the broader framework developed in this thesis.

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<sup>10</sup> Sexton and Barrett's (2005) discussion of capability, capacity and motivation is noted. Unfortunately, they do not appear to have subsequently developed the notion.

In the project context, the COM-B system is considered to describe how the project context and actors' emergent project performance objectives shape a DMU's solution space, providing the conditioning structure for their exercise of agency. A DMU's capability to perform a desired behaviour – both physical and psychological – is reflected in their access to and control of cultural and resource endowments. The opportunity to specify NMS derives from the social and physical contexts within which the behaviour occurs, that is, the specification of the NMS must be permitted and promoted by the conditioning structure imposed by higher levels of the project decision hierarchy without risk of sanction. Figure 28, presents an elaboration of the decision  $D_n$  showing the influence of capability and motivation on the specification decision shaping the solution space of the DMU.

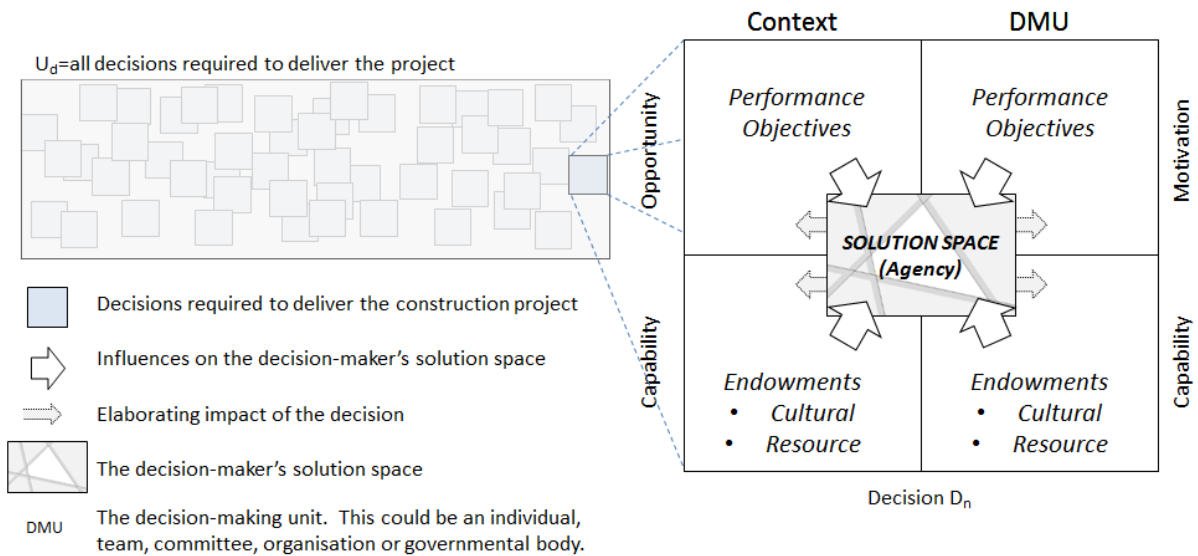


Figure 28 – Structural influences on actor agency – capability, opportunity and motivation

This chapter now explores how a project's emergent conditioning structure influences the DMU's exercise of agency in the NMS specification decision (Objective 3). The discussion integrates the COM-B behaviour system with the morphogenetic view of structure and agency adopted here by exploring the conditioning structure of the specification decision, the specification decision itself, and the elaborating impacts of that decision. First, however, the chapter briefly explores the NMS adoption process on construction projects.

## 9.2 The NMS Adoption Process

The processes leading to NMS adoption on projects can be likened to those required to introduce any innovation to a construction project. The phase one Material Adoption Model (Figure 29) presented a grounded theoretical exploration of this process in a decision flow chart, reproduced at full scale in Appendix C (page 367) and described in detail in Jones (2014). The flow chart synthesised emergent data from this study, in particular non-participatory event AD, Interview 5 and the survey and phase 1 interviews, with literature on the innovation adoption decision (in particular Rogers, 1995). The flowchart was reviewed and validated by senior structural engineers. This innovation adoption process was also explored by Ozorhon, Abbott and Aouad (2014) who adapted Hansen and Birkinshaw's (2007) Innovation Value Chain to a construction context (Figure 30).



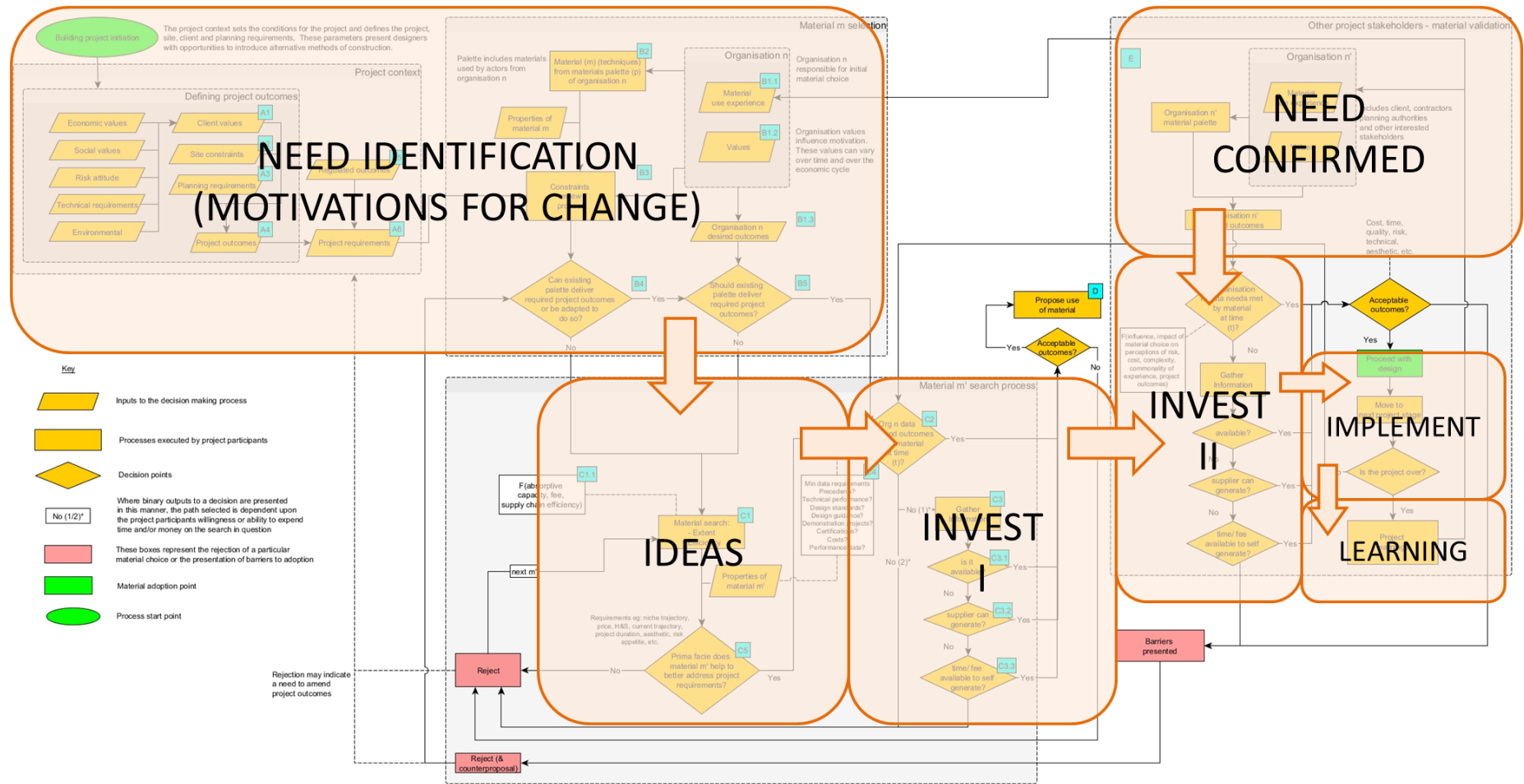


Figure 29 – Overlay of Ozorhon, Abbott and Aouad's (2014) innovation phases onto the Material Adoption Model (Appendix C)

While other generic innovation process models have been produced (for example, Rogers, 1995; Tidd, Bessant and Pavitt, 2001; Sexton and Barrett, 2003b) with slightly differing emphases, and degrees of granularity, the underlying processes described in each broadly reflect the processes highlighted in Figure 30. In this process, a project need triggers the search for an innovation, and once identified, there is a need to invest in the idea to ensure that it is suitable for the project. The ‘innovation’ stage reflects the incorporation of the new technology into the project to deliver the project outcomes. New learning is then incorporated into subsequent projects.

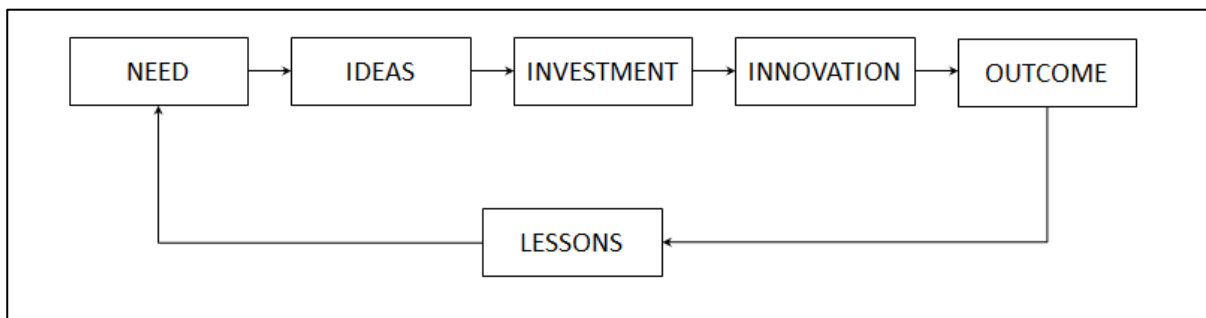


Figure 30 – Phases of innovation adoption  
Adapted from Ozorhon, Abbott and Aouad, 2014, with permission from ASCE

Figure 29 overlays Ozorhon, Abbott and Aouad’s (2014) innovation phases onto the more granular description provided by the Material Adoption Model. The overlay highlights minor, but important, distinctions between the two perspectives. Ozorhon, Abbott and Aouad’s term ‘innovation’ might better be replaced by ‘implement’ (Murphy, Perera and Heaney, 2015) as this better represents the step subsequent to the exploration and testing of the NMS (investment). Further, the word ‘implement’ is more explicitly a verb in this context, and avoids the confusion that ‘innovation’, either noun or verb, can bring. Ozorhon, Abbott and Aouad’s (2014) perspective also overlooks the need for validation of decisions by other PBOs (‘Need confirmed’, and ‘Invest II’ in Figure 29). In turn, the Material Adoption Model could be further modified to consider the outcomes of the process of innovation, including learning, which it assumes simply address the needs identified at the outset of the process. These two perspectives have been combined to create a generic process map of innovation on construction projects (Figure 31).

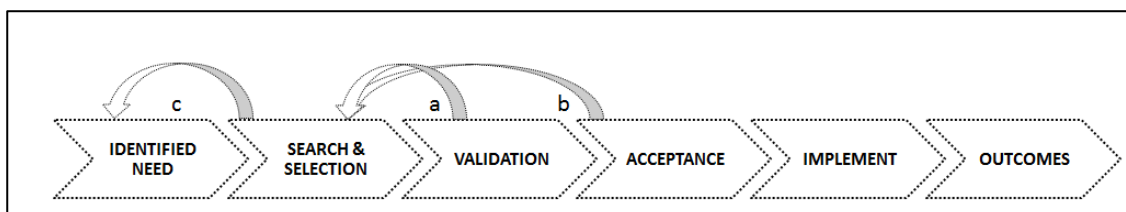


Figure 31 – Generic construction innovation process adopted in the research

Figure 31 describes the innovation process as follows. When a need to innovate is identified on a project, the project team must identify potential solutions to address this need through a process of search. This process explores the solution space described by the specification

decision's conditioning structure. From the options identified, a potential solution is selected and put forward for validation in the specifying company to confirm that it meets the performance objectives established at the point of decision. This proposed solution is then passed to the coordinating PBOs for validation and coordination prior to implementation to deliver the project outcomes. Each of these stages are explored in more detail in Sections 9.3 and 9.4 below.

The innovation process in Figure 31 is presented as broadly linear. However, in practice, the process has been observed to involve several feedback loops. These arise if, for example, a proposed NMS cannot be shown to perform sufficiently to enable validation by the specifying company (loop a), or it is rejected, rather than accepted, by the coordinating PBOs (loop b). A further feedback loop (c) has been reported by an industry participant where a PBO was unwilling to undertake a search for an NMS, and suggested that the client's performance objectives be revisited as they could not be met. This position challenged the delivery of the client's adopted project performance expectation. In this case, the client sanctioned the PBO, replacing them with a team that was willing to undertake the necessary process of search.

Having identified a need to adopt an NMS, project actors will consider the relative costs and benefits to themselves, their host and other PBOs, and the project itself, of embarking on the process described in Figure 31. The remainder of this chapter explores the NMS adoption process and the influences on the specification decision, discussing the factors that a DMU considering specifying an NMS might consider.

### **9.3 The Decision's Conditioning Structure: Performance Objectives Motivating NMS Specification**

#### **9.3.1 Performance Gaps and Improvement Trajectories Motivating Implementation**

Section 7.11.5 describes how, in the face of uncertainty, clients, PBOs and DMUs will adopt assumptions and performance objectives that are more or less 'regime-like'. The dominant material solutions (DMS) used in construction have evolved over time to address the regime performance objectives effectively. However, where sanctionable performance requirements or expectations emerge in a project that extend beyond these *de minimis* 'regime' performances, the project team, typically well versed in the use of DMS, may be faced with a performance gap (Figure 32) (or 'innovation gap' in Sexton and Barrett, 2003b) that causes the DMS to fall outside of the DMU's solution space. That is, the DMU may be unable to meet the non-regime performance objectives through the application of their prior experience in materials. This can occur, for example, if there is a sudden and dramatic change in the building regulations or market demand, or if a client has articulated novel performance requirements due to their drivers of value. If a performance gap relates to project requirements, the entire project might be at risk, a failure to meet project expectations may lead to client dissatisfaction or risk of sanction against the DMU for failing to meet relevant performance objectives. In this way, performance gaps provide specifiers with the opportunity to consider the use of an NMS with

performance attributes that address the gap. This idea of perceived performance gaps also operates at the level of the material manufacturer. However, the manufacturer is able to amend their own production processes to address a perceived performance gap, while a construction client, or indeed, their designers, will typically need to engage with manufacturers to address the gap.

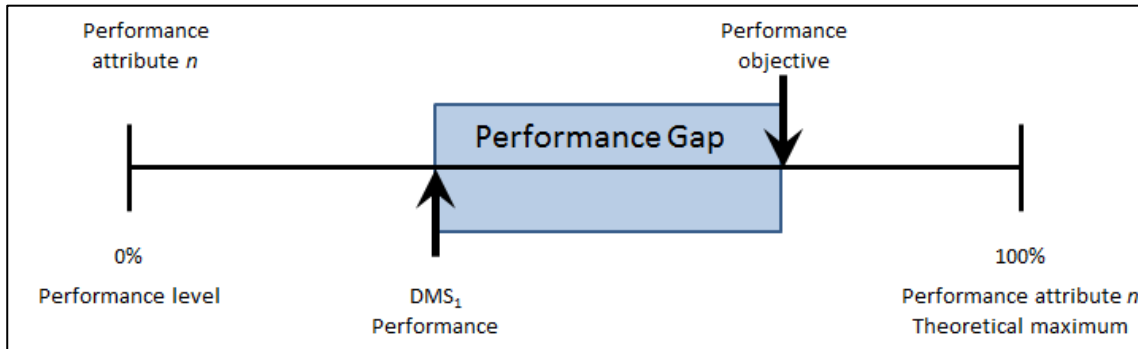


Figure 32 – Performance objectives and performance gaps

Performance gaps can also arise from the performance aspirations of project participants, these gaps are described here as ‘improvement trajectories’ (after Christensen, 1997a). Pursuit of these aspirations may be explicitly incentivised or promoted, with the context, client, or PBO aligning the incentives with DMUs’ performance aspirations (data point D). In a commercial environment, if delivering on project performance aspirations can lead to cost savings, these can be distributed through some form of ‘pain/gain sharing’ agreement (Interview 7). For example, if reducing the embodied GHG in a project can be shown to reduce costs for a client, a contractor could be incentivised with a share of the financial gains from reducing embodied GHG. While a failure to deliver on a performance gap leads to sanction, failure to deliver on the performance aspirations is unlikely to do so (Section 8.3.2.2). It has been observed during the study that if considered at all, embodied GHG and resource efficiency are typically treated as improvement trajectories, rather than sanctionable performance gaps (data point AL, Interview 7). This was reinforced by one industry participant who spoke of a lack of functioning sustainability drivers at the point of specification.

Addressing perceived performance gaps and improvement trajectories (collectively ‘performance needs’), therefore, can provide motivated actors with the opportunity to change their specification behaviour. The next sections discuss the nature of these performance needs.

### 9.3.2 Market-Based Performance Gaps and Improvement Trajectories

Organisations can be motivated to change their decision-making behaviour in pursuit of their long or short-term value objectives (Appendix A). For example, the establishment of a new construction project means that a client has determined that a new building will create value for them in some way (after Spencer and Winch, 2002). The market for bespoke buildings can therefore be considered to be demand led: the construction industry responds to the client performance objectives articulated as part of this demand. Over time, the performance

demands of building occupiers, and construction clients, change, and buildings must be delivered to provide ever improving performances (Gann, 2000). For example, at the time of writing, there is an increasing focus on wellbeing at work, which is considered to improve longer term productivity, staff retention and performance. For example,

*“[They categorise it as] health, wellbeing and productivity in order to try and bring in commercial considerations of functional performance of workplaces”*

*Data point 9*

As these demands change, new performance gaps are created (cf. passive niches, Section 7.11.6). Typically the solutions to address these slowly developing, niche, market-based performance gaps can be anticipated and developed by suppliers seeking competitive advantages, and incorporated into projects with relatively little disruption, or can be designed as ‘end-of pipe’ technologies (Unruh, 2002) to facilitate simple integration into the built form. However, at this time, there is little evidence of sufficient owner or occupier market demand for low embodied GHG materials in construction to motivate the development and implementation of NMS on projects (WBCSD, 2012).

Indeed, while performance needs could relate to any one of the myriad potential decision variables (Section 8.3.3), during the study, the performance needs most frequently observed in construction are those relating to objective measures of value (Mills, Austin and Thomson, 2006) such as health and safety, time, cost and the associated criteria of buildability and productivity (data point O). For example, a structural engineering director put it bluntly:

*“ [Clients] don’t want innovation, they [just] want it cheaper [...], and quicker.”*

*“Very, very rarely will a client pay over the odds for something just because it’s more sustainable ...”*

*Interview VI*

This cost/time reduction narrative is continued in the recent Farmer Review (2016) and the UKs Government’s Construction Industry Deal (HMG, 2018) with their focus on improving the productivity of the construction industry (*value* of outputs / *value* of inputs). Data points F, AJ and AO and Interview II also highlighted an aversion to pro-sustainability change that was not profitable in and of itself, a feature reinforced by the quote from 1887 used to introduce this chapter and other studies in the literature (for example Ozorhon, Abbott and Aouad, 2009; Ozorhon, Oral and Demirkesen, 2016). Risk was also frequently discussed, but typically in terms of delivery risks, again relating to the delivery of time and cost performances. Jones et al. (2016) provide a description as to why the performance objectives of certainty (risk reduction) and capital cost (underpinned by a cost of time) typically become the dominant improvement trajectories in the construction project once the contractor has been appointed. Transgressing expectations relating to these performance attributes can lead to sanction under the terms of engagement typically included in contracts.

These dominant discourses represent improvement trajectories of the cost and time efficiency of delivery of a regulated minimum (regime-like) performance, subject to context and client performance objectives (potential niches), and reducing the risks of exposure of post-completion policing and enforcement costs. There is also an increasing focus on the Health and Safety performances of the delivery process, recognising the potential criminal and financial sanction for injury to construction workers and building users (HSWA 1974 s33). The opportunity to pursue enhancements to these improvement trajectories of risk, cost, time or health and safety can more readily motivate change in specification behaviours. It will be noted that without sanction or incentive, reducing embodied GHG through NMS specification does not fall under these headings. The imposition of some form of resource taxation could introduce a competitive aspect to the reduction of embodied GHG on projects (data point AZ).

Organisations with longer (temporal) decision horizons may also identify value in more remote financial benefits resulting from the process of NMS implementation, and seek embodied GHG reductions in pursuit of that value. This reflects the extension of the temporal decision horizons for this contractor, from the very short-term, regime-like focus of the project, to the longer term value of the ongoing business, driven by their perception of *“look[ing] at the market, ... at the way things were going”*. This longer term perspective on financial value was also evident in descriptions of Anglian Water’s approach to reducing embodied GHG to address changing regulations. An example of the extension of decision horizons arose with a building project that formed part of a larger development, the London 2012 Olympics (Interviews 2, 8). In the delivery of the velodrome, a form of cable net roof structure was proposed that was novel in the UK. While the proposal was considered a *“risky move”* having not been used in the UK before, the use of the cable net could reduce the build time from that assumed at the project outset by approximately 6 months. This allowed the project team to *“walk off the park before anyone else”*, reducing the anticipated risk of skilled labour shortages elsewhere in the run-up to the delivery date for the other venues that could threaten the delivery of these other projects to time – avoiding future losses elsewhere. While considered as separate building projects, it was important for adoption that the velodrome was part of a wider time-constrained development programme for a single client.

This demonstrates how project actors’ conceptions of value can incentivise them to invest in NMS implementation to pursue value (Appendix A). Where the client or their agents perceive a performance gap relating to a project requirement or expectation, they are able to align the interests of the project actors to ensure that value is delivered (after Bell, 1994; Male et al., 2007). This alignment can be achieved through the choice of appropriate procurement route (Kumaraswamy and Dulaimi, 2001; Zimmerman, 2007) or the management of supply chains (Wamelink and Heintz, 2015). Requiring or incentivising PBOs to address performance gaps, or sanctioning their failure to do so, can provide unmotivated project actors with the motivation to propose and deliver NMS by excluding the DMS from their decision solution spaces.

Ozorhon, Oral and Demirkesen (2016) identify the project level drivers of value from NMS (innovation) implementation in Turkey as:

- decreases in project cost;
- decreases in project duration;
- increases in productivity; and
- increase in client satisfaction.

These categories are unsurprising in the context of the pursuit of the regime-based improvement trajectories of the construction sector. However, Ozorhon, Oral and Demirkesen also highlight the associated firm level benefits relating to competitiveness and longer term value creation:

- experience;
- image enhancement;
- improvement of technical capabilities;
- improvement of managerial capabilities;
- long-term profitability;
- intellectual property; and
- future business opportunities.

While clearly not exhaustive, some of these potential PBO outcomes from projects will be reflected in the PBO's performance objectives for their work on a project, and will influence the decisions they take and value investments that they make. The benefits that PBOs seek from engagement with projects are longer term drivers of value, reflecting the fact that the PBOs have an ongoing existence; they pre-exist the transient project on which they deploy their endowments (after Winch, 2014) and will normally continue to exist once the project is complete. This suggests that PBOs engaged in the industry for the long term can be motivated to invest in NMS to protect their longer term survival, even when they will only pursue innovation to enhance delivery on projects.

### **9.3.3 Mission-Led Performance Gaps**

One interviewee continued this market-based cost and time narrative, but with an interesting caveat:

*"We're not interested in innovation for innovation's sake [...]. We would innovate to save on time or money, or improve on the other [...] strategic goals."*

*Interview 7*

The interviewee described how their organisation (a quasi-public body) has adopted non-regime based performance objectives, around *inter alia* skills, diversity and education. These non-regime performance objectives reflect the derivation of value from a form of organisational mission (Mazzucato, 2016) beyond the purely financial and short term. A client's drive to achieve their mission can create performance gaps and improvement trajectories attracting

investment to address performance variables beyond those dominating the industry (see, for example, Gerrard et al., 2015; Jones, Martin and Winslow, 2017).

*“Sod the commercial department we want the right solution.”*

*Data point 9*

Such mission-led performance gaps and improvement trajectories challenge DMUs to consider not only whether dominant solutions *can* be used on a project, but whether they *should* be. That is, to consider whether the DMS reflects fully the value concerns brought to bear on the specification decision by the hierarchy of decision variables. This notion was explored in the Material Adoption Model (Figure 33 presents a relevant extract). The flow chart extract in Figure 33 shows how a specifying PBO will explore a project’s constraints (box B3) using their prior experience and value concerns (boxes B1.1, B1.2) to establish whether their existing awareness and knowledge of materials, that is, the contents of their solution space (box B2), *can* address the context and client performance objectives for the project (box B4). Subsequently, in the face of their own performance objectives (conflated in box B1.3) informed by their drivers of value (loosely described as ‘values’ in box B1.2), the specifying organisation considers whether this prior experience *should* be used (box B5). If the response in box B4 is no, a performance gap is established at the level of the client or context creating the opportunity to implement an NMS on a project. A negative response in box B5 creates a performance gap at the level of the specifying PBO. However, if the outcome to both of these questions is yes, the opportunity for the specifying organisation to propose an NMS will be missed.

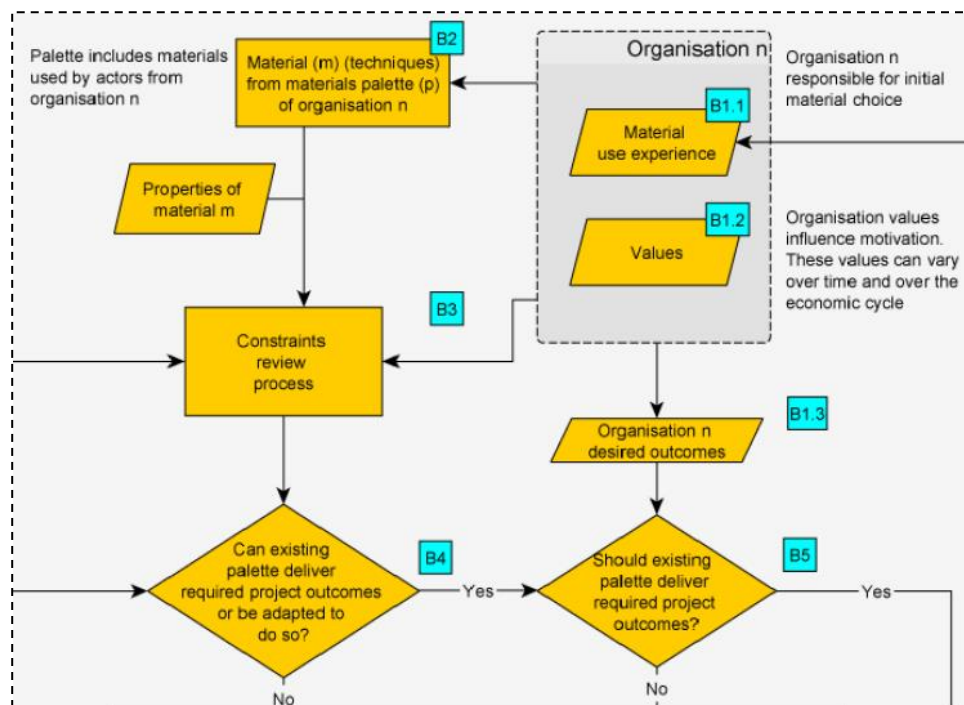


Figure 33 – Performance objectives as motivations for change.  
Extract from the Material Adoption Model

Addressing a context or client created performance need in pursuit of project or organisation level outcomes provides specifying DMUs with the opportunity / motivation to modify their



decision-making behaviour and consider specifying NMS on a project. Further, performance needs provide an indication of the performance attributes in which a project should improve, setting a vector for improvement and innovation. The position is summarised in Figure 34.

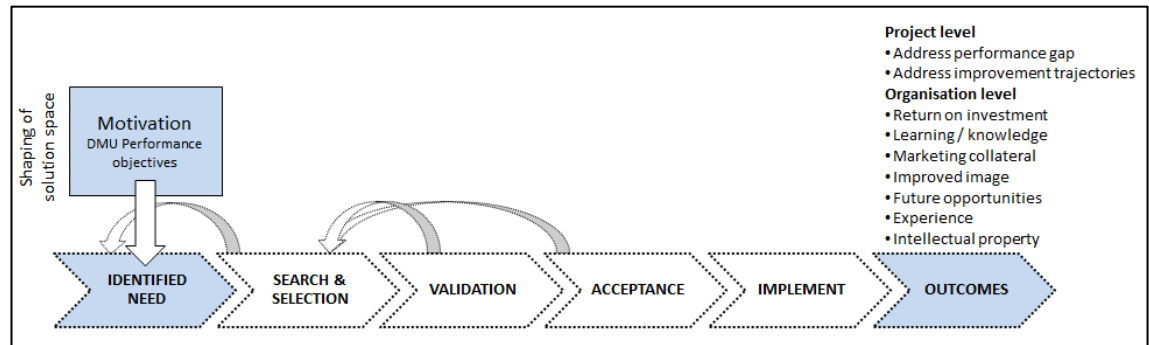


Figure 34 – Performance needs motivating the search for novel material solutions (NMS)

#### 9.3.4 Locating the Source of Performance Gaps and Improvement Trajectories

A project's performance needs can arise from any one of the levels of the project hierarchy; context, client, PBO or DMU (Section 8.3.3), and be subject to different degrees of constraint: requirement; expectation; or aspiration. Situating a performance need in this context provides a DMU with insight as to the sanction that might result from non-satisfaction of the performance need.

		Degree of constraint / value imperative			
		Requirement	Expectation	Aspiration	
Source of decision variable	Context	Meet building & planning regulations			External objectives provide opportunity
	Client		Delivery to cost and time Project Satisfaction	Exceed delivery expectations	
	PBO		Meet profit expectations	Exceed delivery expectations Learning opportunities	Internal objectives provide motivation
	DMU			Improved embodied GHG performance	

Figure 35 – Need Location Matrix – Identifying sources of performance needs

Figure 35 presents a simple 'Need Location Matrix' that can be used to locate project actors' performance objectives and performance gaps for a project. It shows, by illustration, a DMU that establishes a value-based performance aspiration to improve the embodied GHG of the project at hand beyond that provided by the DMS. The host PBO has defined an expectation of

profitability at a certain level that they aspire to exceed, and aspirations to learn from the project. The client has an expectation of project delivery on time and budget. The decision to specify a low embodied GHG material will have elaborating impacts (Section 9.4, below) that may jeopardise PBO and client expectations leading to sanction.

Indeed, despite the typically market-based focus on delivery cost and time, a DMU remains at liberty to address their own conceptions of value in a decision by introducing new performance objectives to a decision where their external context is silent on it. While this can create a performance gap at the level of the DMU, other project team members may not share their conceptions of value, and hence not recognise the particular performance need. There is a risk those validating the decision within or without the host PBO will reject or sanction the resulting specification decision. That is, unless the client, PBO or indeed the DMU are willing to invest the necessary time and/or money to ensure that the DMU's aspirations are met. At data point AT, a main contractor described how their delivery processes ensured they didn't go beyond the minimum standards stipulated by the client and regulation so that they don't get sued for, or risk slender profit margins, by over-delivery. They deliver what the client asks for, nothing more. For example, a project architect may wish to address perceived design-based performance gaps, while QSs, having limited tools with which to translate design implications to the financial terms in which they are typically assessed, might not appreciate the nature of the value that good design can bring (CABE, 2002). This may lead to the QS lacking the motivation to accept the specification of a potentially more expensive NMS onto a project.

*"[embodied GHG is] not a check box on the QS's tick sheet. So for all intents and purposes, it has no value"*

*Interview 1*

The higher and further left a performance need driving NMS specification sits on the need location matrix the more likely the need is to be addressed in the project. This is, in part, because the sanction on projects and project actors for transgression of context requirements can be severe. It also affects a broader population, and there are fewer superior performance objectives that might be transgressed by addressing the contextual performance needs. For example, where context decision variables create the performance gap through site conditions or regulatory requirements, the gap will be limiting on the solution spaces for all of the decision-makers engaged in the project delivery process, and will be reflected in the process of project coordination (Section 8.5.3). Similarly, client-imposed objectives will influence the work of the whole project team.

## **9.4 Elaborating Impacts of the NMS Specification Decision**

### **9.4.1 Elaboration: Exploring the Impact of the NMS Specification Decisions**

As the data in Chapter 5 suggests, identifying, researching and validating an NMS takes time and money. NMS specification then can create an anticipation of additional transaction costs

(after Figure 37 and Section 7.8). Indeed, the more novel the technology, the higher the anticipated impacts on the time and cost of project delivery (Crossrail, 2013). However, due to the reciprocal interdependence of decisions and decision-makers described in Section 8.5.3, a specification proposal by a DMU in one PBO can have elaborating implications for both the host PBO, and other project PBOs. This section explores the elaborating impacts of a decision to specify an NMS on a construction project on the project and project actors' performance objectives over the foreseeable duration of the project (Figure 36).

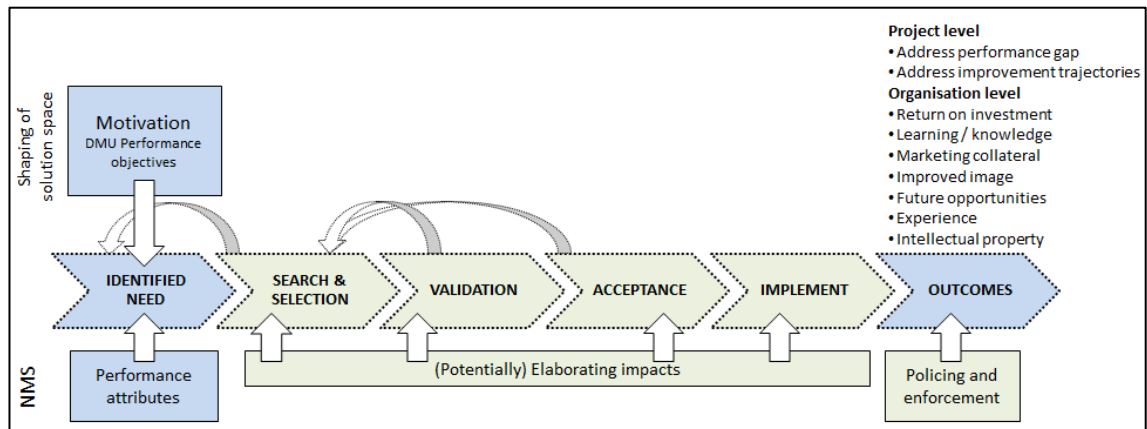


Figure 36 – Elaborating impacts of novel material solution (NMS) specification.

Section 5.3.8 described five broad approaches to addressing a project's performance needs, each having an increasing elaborating impact on the project after specification:

- Search for a suitable product on the market.
- Extend existing practices.
- Import proven technologies from other sectors.
- Radically adapt existing practices or solutions
- The invention of a new technology.

This thesis focuses on the final three 'explorative innovations'. This form of innovation has received relatively little attention in the literature (Larsson and Larsson, 2018). The following sections now explore the elaborating impacts that might be anticipated when considering the implementation of an NMS on a construction project to address identified performance needs.

#### *The Influence of Transaction Costs on the Specification Decision*

*"At the end of the day, what matters is the money"*

*Interview 1*

Section 7.8 describes how transaction costs relating to search, learning, bargaining and policing and monitoring are anticipated in project decisions. Through a process of modelling, Qian et al. (2014) demonstrated that these transaction costs were the biggest impediment of 'green building' market penetration. In light of the known human biases of loss aversion, and the related findings of prospect theory (Kahneman and Tversky, 1979), which studies decision-

making under risk and uncertainty, it becomes unsurprising that barriers are presented in the face of an expectation of significant additional costs. Indeed, because NMS are by definition, new to a context, and unless they arrive on the market replete with the required certifications, warranties and performance documentation they will be associated with search, information creation, learning, and monitoring costs.

Figure 37, developed through the researcher's observations and reflections, shows how a performance gap – a perceived need for the NMS – leads to active search and the anticipation of further transaction costs for search, information, learning, and policing and enforcement. However, the level of these anticipated transaction costs is entirely subjective and influenced by many factors, including an actor's endowments of knowledge and experience. The factors influencing the anticipation of transaction costs are typically beyond the control of a consultant wishing to specify NMS.

In the presence of uncertainty, therefore, the anticipation of transaction costs can be a significant influence on the NMS specification decision, but it is not the sole determinant. If that were the case, then novel materials would rarely enter the market. Appendix A describes how these and other anticipated costs are factored into decision-making relating to NMS specification on construction projects, reducing the motivation of actors with short-term decision-making criteria to specify and implement novel technologies.

#### *A Question of Time*

As well as the anticipation of transaction costs, the need for search, learning, bargaining and monitoring will also cause actors to anticipate the use of project time budgets. Where delivery has been planned on the assumption of the use of the dominant solutions, the ability of schedules to accommodate additional search and learning will be severely restricted.

#### **9.4.2 *Elaborating Impacts: Search and Selection - Finding and Choosing an NMS***

Once a need for an NMS has been identified, the PBO (DMU) with responsibility for specifying a solution during conceptual and detailed design, typically the design team (Mackinder, 1980; Emmitt, 2006) searches for a solution to address the perceived performance need. Increasingly, contractors and specialist sub-contractors are taking over the role of specification at the final stages of the project due to changes in procurement practices (Emmitt, 2006). The process of search happens at several stages of the design process: conceptual design, detailed design and specification (Emmitt, 2006). The process differs slightly with each stage. While it is beyond the scope of this thesis to explore these differences in detail, an overview of the process will be provided informed by data points A,B and D.

The first stage of the search process might be to review the DMU's solution space to see if there are any other options readily available to the DMU – that is, can they specify materials they already know about (Figure 33). This has been found to be a typical response to the selection of construction materials by architects (Mackinder, 1980).

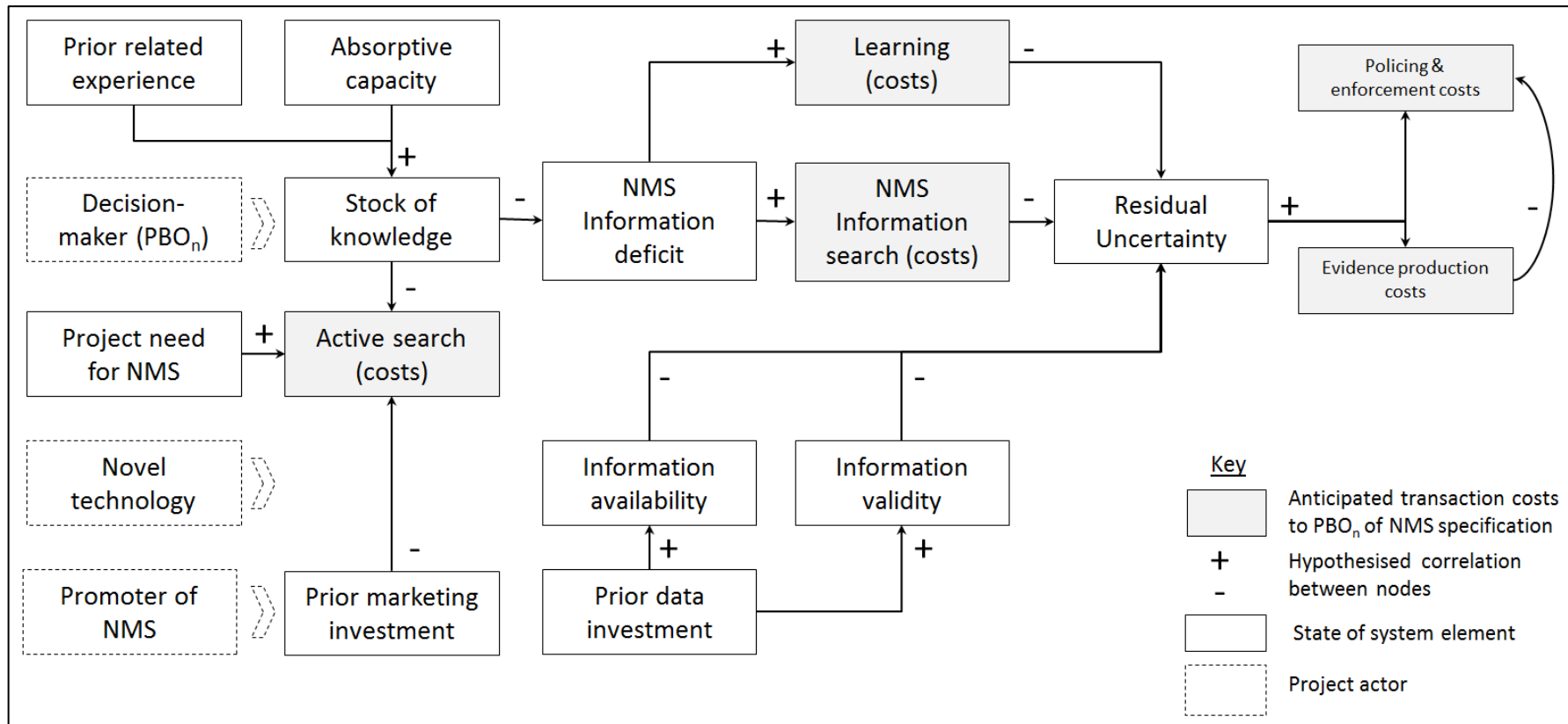


Figure 37 – Simplified system diagram of the abducted influences on transaction costs anticipated due to an information deficit

It is notable that one of the key virtues of steel and concrete is that they are immensely versatile materials that can be adapted to almost any construction situation, eliminating the need for the time-pressed designer to extend the exploration of their material solution space.

If the DMU's experience and knowledge do not provide a suitable solution, a search commences to identify solutions to specify for the project. This search process can take place in a number of ways, for example, using in-house product libraries or trade literature (Mackinder, 1980, data point D), on-line databases (data point A), internet search or simply by asking colleagues or suppliers (data point B). This search and the subsequent selection process – that is, the specification decision – can be relatively rapid, with inappropriate solutions being identified and discarded quickly. Indeed, due to the limited time typically allocated to the specification process (Emmitt, 2006), this rapidity is necessary if designer performance objectives over profitability are to be met. Where the cost of making a decision is high, it can be adaptive to sacrifice an optimal outcome for speed (Sih, 2013).

If a performance need is uncommon, the search and selection process may extend beyond the typical market solutions and can take considerable time, eating into fixed fee budgets, putting financial outcomes at risk. Accordingly, unless a range of potential solutions are to be presented for client consideration, search will typically stop when a solution that meets the project sanctionable performance objectives is identified, rather than seeking 'the best possible' solution. That is, the selection process is typically one of satisficing (after Simon, 1955; Caplin, Dean and Martin, 2011), rather than optimising. Clearly, where a dominant solution is specified the costs and time committed to the process of search and selection is avoided.

Early in the research process, a product database was considered as a potential output to improve the efficiency of the search process for the project sponsors (data point A). However, it became evident that the development and, in particular, the maintenance of a database by an SME with multiple requirements, addressing the needs of structural engineers, sustainability advisors and graphic and product designers would be time and cost prohibitive. Other free to use databases were identified and proposed for use instead.

#### **9.4.3 Elaborating Impacts: Validation - NMS and Technology Readiness Levels**

*"If you're picking up a new product as a designer, you've obviously got to do a lot of research, you've got to understand what it is you're playing with...". "You're going to be taking a risk on it, you're going to want to do some more work [but] your lump sum fee [...] doesn't allow you to do so"*

*Data point 9*

#### **NMS Relative Performance Advantages and Disadvantages**

Where a DMU's solution space precludes the use of a dominant solution, the output from the process of search is one (or more) NMS that might be suitable to address the identified performance needs shaping the DMU's solution space. Each of the identified NMS will demonstrate performance attributes that the dominant solution does not. In this way, an NMS can be described as having a

‘relative advantage’ over the DMS in the performance attribute in question (after Rogers, 1995; Suhr, 1999). By extension, the DMS has a ‘relative disadvantage’ in that same performance attribute. When this relative advantage addresses the performance needs of the project and project participants, the chances of an NMS being adopted onto a project are increased.

However, if an NMS promoter or DMU cannot satisfactorily demonstrate that the other project members’ sanctionable performance objectives established at the point of specification can be met, irrespective of the underpinning assumptions, the decision to specify an NMS is likely to be resisted. This inability to demonstrate the necessary performances can arise from two sources:

- Performance deficits<sup>11</sup>. The performance attributes of a proposed solution demonstrably fail to address the sanctionable performance objectives of the project or PBOs who must accept the implementation of the NMS. These deficits are typically considered in terms of technical performance attributes, cost or time impacts, but might relate to any performance objective or decision variable. The local and consistent availability of the NMS was frequently cited as an attribute of concern, along with the presence of two or more suppliers, seeking to address the risk of hold-up (Gieseke et al., 2014; Chan et al., 2018) (data point 9, Section 5.3.7). Performance deficits can also lead to the NMS being excluded from the project solution space;
- Information deficits (cf. Figure 13). These arise when there is insufficient evidence to support the performance attributes to the NMS. Such deficits lead to uncertainty over outcomes, the anticipation of transaction costs and the resulting perception of risks to performance objectives.

When faced with a performance deficit in the NMS in a sanctionable performance objective, two broad options are available to the NMS specifier, amend the NMS, or amend the solution space:

- Re-engineering or augmenting an NMS’s performances allows the NMS to move into the decision solution space by addressing the performance attributes that previously excluded it. The conditioning structure of the solution space remains unchanged, but the NMS performance attributes change. For example, concrete is very poor in tension, reducing the ability to deliver longer clear spans, a typical improvement trajectory providing additional flexibility and useable floor space. The introduction of steel reinforcement into concrete enhanced concrete’s performance in tension, allowing reinforced concrete to achieve longer spans. Similarly, the addition of Portland Cement into rammed earth walls (stabilised rammed earth) addresses durability performances of non-stabilised rammed earth that might preclude its use (data point B). The application of subsidies or grants attracted by the NMS can address the cost performances of projects (Woolley, 2013).
- The solution space can be altered by amending or abandoning the performance objectives in which the NMS is deficient (feedback loop c in Figure 31). If the relevant performance objective arises from the DMU they can make a value-based decision to exclude the performance

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<sup>11</sup> This term is adopted in distinction to a ‘performance gap’. A performance gap is considered to be created by demand (demand pull), while a relative performance deficit is considered a supply side shortfall. Were the NMS to demonstrate a relative performance advantage that aligns with the project or DMU’s improvement trajectories, technology push innovation might be seen.

objective to avoid sanction. The NMS performs the same, but the constraints on the solution space are (re)moved. For example, an architect might dismiss consideration of cost to select a material that achieves a certain architectural effect. However, it must be within the power of the DMU to influence the flexed performance objectives at the point of decision. If the sanctionable performance objectives are imposed from above in the project hierarchy (Figure 22, Figure 35) the DMU's dismissal of a performance objective is likely to lead to the proposal being rejected, or sanctioned.

Clearly, these two strategies can be applied concurrently.

#### *Information Deficits - Developing Certainty over NMS Performances*

Assuming that any relative performance disadvantages of the NMS can be addressed, ensuring its presence in the project specification solution space, the relevant performance attributes must still be validated to the satisfaction of the specifying PBO (data point J). This is to give the specifiers confidence that the product will deliver the performances required by the DMU, their host PBO, the client, and coordinating PBOs, reducing the risk of later sanction or rejection. With long established materials, or well-funded material suppliers, this validation is typically possible through a review of performance certifications addressing the 'regime' performance objectives for projects. Confidence is further increased by the availability of warranties provided by a supplier.

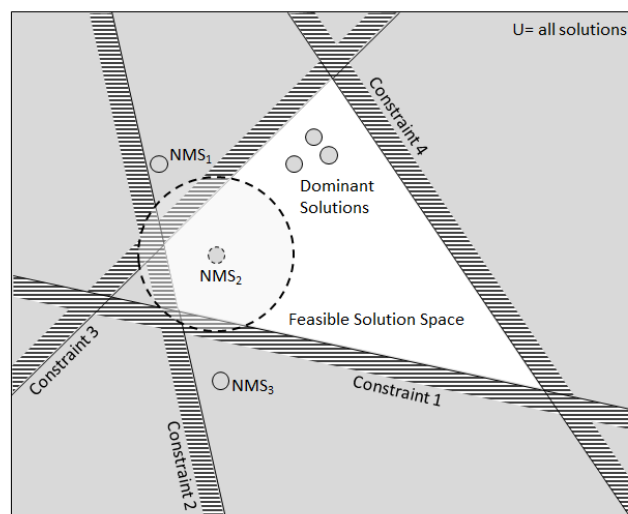


Figure 38 – The effect of uncertainty on NMS selection

Indeed, the process of specification and site-based operations typically relies on the institutions of International, European or British standards, or BBA certification to demonstrate the performances of the products. However, in the case of an NMS, such certification and evidence of performance in use may not yet be available. The associated uncertainty can lead to resistance (data point Q). Figure 38 shows how performance uncertainty can cause an NMS to be considered to fall outside of the decision-maker's solution space. Deficits in information or evidence of performance can mean that there is a possibility that the performance delivered by an NMS may cause the project to perform below project requirements, or expectations, risking sanction.



Figure 39 shows a redacted extract of a contractor's 'Material Approval Request' form demonstrating the breadth of information that might be required before a material can be introduced to a project site. While the form indicates that evidence need not always be produced, project actors can leave themselves open to litigation costs if they are unable to demonstrate that they confirmed that the material performances were suitable. The certification process can take considerable time and money, and represents a significant barrier to market penetration for suppliers (data point AA, observation 9). Specifiers, limited by the need to deliver a cost-effective service, are rarely willing or able to invest to demonstrate the necessary performances themselves (Jones, Martin and Winslow, 2017, however, provide a counter-example provoked by client performance objectives).

Materials Approval Request		MAR
(To be used in accordance with )		
Date: 18/05/2017	MAR No.	Rev 01
SUBCONTRACTOR/SUPPLIER/SELF DELIVERY (if applicable)		
SPECIFIED PRODUCT OR SYSTEM (description brand/name consistent with specification/drawing requirements)		
PROPOSED PRODUCT OR SYSTEM (Proprietary brand/name and grade)		
PROPOSED MANUFACTURER (Manufactures name and address – not the supplier - include factory, works, plant, quarry, etc.)		
Is the supplier of the Material ISO 14001 accredited?	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>	if Yes, add to list of supporting documents
CONTRACT SPECIFICATION (including clause and status – if no specification state "None")		
DEVIATION FROM SPECIFIED PRODUCT OR SYSTEM TYPE, IF ANY (i.e. white gloss paint)	YES <input type="checkbox"/> NONE <input type="checkbox"/> N/A <input checked="" type="checkbox"/>	If product or system not specified indicate as N/A.
DEVIATION FROM SPECIFIED GRADE PRODUCT, IF ANY (i.e. white gloss paint to BS12345)	YES <input type="checkbox"/> NONE <input type="checkbox"/> N/A <input checked="" type="checkbox"/>	If both None, only to be approved by CRE and QDM
DRAWING REFERENCE (including status)		
LOCATION WHERE TO BE USED		
OFFSITE OR PRE DELIVERY INSPECTION REQUIRED	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>	if Yes, add to list of supporting documents
ON-SITE MOCK UP REQUIRED	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>	if Yes, add to list of supporting documents
SAMPLE REQUIRED	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>	if Yes, add to list of supporting documents
TECHNICAL LITERATURE / CATALOGUE REQUIRED	YES <input checked="" type="checkbox"/> NO <input type="checkbox"/>	if Yes, add to list of supporting documents
COMPLIANCE/TEST CERTIFICATES SUPPLIED	YES <input checked="" type="checkbox"/> NO <input type="checkbox"/>	if Yes, add to list of supporting documents
ELECTROMAGNETIC COMPATIBILITY (EMC) REQUIRED (for all electrical supplied items)	YES <input type="checkbox"/> NO <input checked="" type="checkbox"/>	if Yes, add to list of supporting documents

Figure 39 – Contractor material approval request form (extract)

Information deficits relating to key performance objectives can result in perceptions of uncertainty and risk to the delivery of performance objectives. One focus group participant described the situation resulting from this uncertainty: *"It's terribly easy to kill innovation by putting too much risk in there [...] you have to have the science to back it up"* (data point 9). This uncertainty must be addressed to the satisfaction of the specifying team to protect against future monitoring and litigation costs. In their process of validation the specifying DMU may consider other PBOs' requirements. However, the extent to which they do so will be a function of their decision horizons and the constraints imposed on them by their host PBO and their contract for services. However, the need for additional data is contingent upon the technology being proposed. Accordingly, the evidential endowments of technologies – their market readiness – are now briefly explored.

### *The Contingent Nature of Information Deficits*

Section 5.4.3 describes the observed approaches to identifying solutions to address performance gaps, and how they each have distinct impacts on the need for performance validation, from the simple use of information from the supplier through to the creation of full-scale prototypes and fundamental research via the use of simple or sophisticated computer modelling. These empirical observations – as presented – can be considered to represent the search for solutions at differing levels of technology readiness (Appendix E), with their associated needs for further validation and verification.

Each client, PBO or DMU will have their own information demands, existing endowments (Section 9.5 below), and tolerance for residual uncertainty relating to an NMS at any given point in the project life cycle (Figure 40). Therefore, while it is possible to provide generalisations about what performance data might be required for an NMS, typically information relating to contextual performance requirements, the scale and scope of the information deficit for an NMS is, once again, contingent.

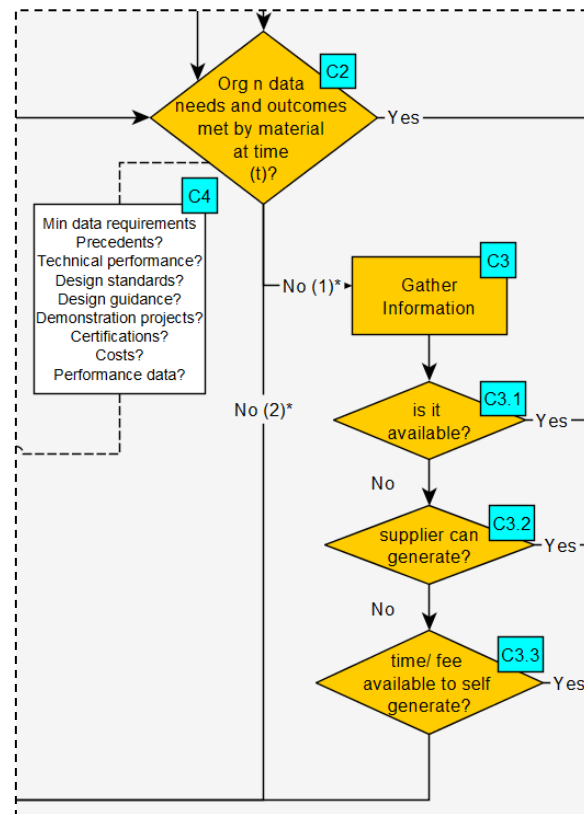


Figure 40 – Means of addressing information deficits  
Extracted from the Material Adoption Model in Appendix C

Irrespective of the scale and scope of the information deficit, three broad approaches to addressing information deficits have been observed in practice (Jones 2014, the Material Adoption Model, Figure 40, validated with senior structural engineers):

- Information collation (box C3.1, Figure 40). The data may already be available through accreditation, precedents, or testing certificates, for example. The role for the DMU is simply to locate and gather the relevant information.
- Promoter creation (box C3.2). Where the relevant information has not been produced or appropriately certified, the NMS supplier or promoter might be able to generate the relevant information, with or without certification. This process can be costly and time consuming for the supplier. Young companies promoting NMS may not have adequate resources to create the attribute data (data points K, AA);
- DMU co-creation (box C3.3), in which the DMU develops certainty over the NMS's relevant performance attribute data through its own testing and experimentation: that is, learning by doing (Arrow, 1962; Pisano, 1994). This investment may be funded by the project on which the NMS will be deployed.

Whether a DMU attempts to gather data beyond the first stage is determined by the location of the performance need in the Need Location Matrix (Figure 35), the time and cost impacts and benefits for specifying the NMS, and the sanction for failure to address the performance need.

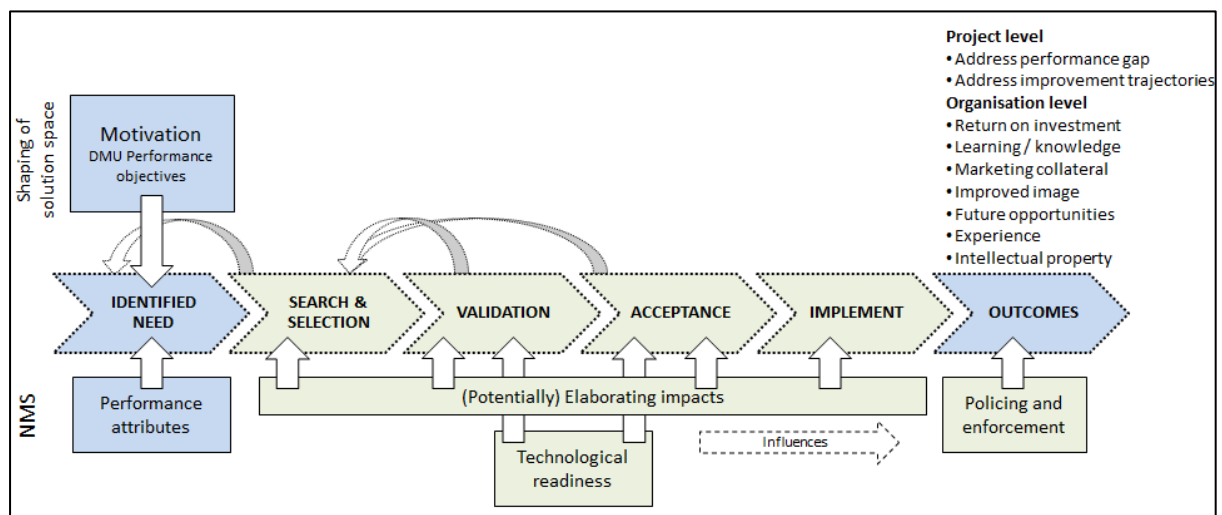


Figure 41 – Influences of Technological Readiness Levels (TRL) on the innovation process

As with the five approaches to developing solutions to address performance gaps described in Section 5.4.3, these options are described in ascending order of time and cost impacts (including transaction costs) on the DMU: that is, the investment of time / money required to develop sufficient performative or evidential capability with the NMS. The absence of a robust evidence base, covering a long period of service operation can also increase the expectation of costs (transaction costs) that might be incurred post-completion in policing the performance in-use and enforcing any necessary legal sanctions through failure. Figure 41 highlights where NMS's Technology Readiness Level (TRL) influences the innovation process on construction projects creating an expectation of additional project costs and time through NMS specification and implementation.

A DMU's proposal to specify an NMS, therefore, can create an expectation in their host PBO of an additional cost or time burden on their project activity. Where, at the point of specification, limits have not been set to time and cost performances, this might be acceptable to the PBO (Section 8.6.3).

However, where sanctionable time or cost performance objectives have already been established at the project or PBO level underpinned by the assumption of the use of DMS, the proposed specification introduces risk to the delivery of these project performance objectives, and may be resisted.

#### **9.4.4 Elaborating Impacts: Acceptance of Proposed NMS by Coordinating Specifiers**

*“... quite a lot of clients are interested in sustainability, as long as it's cost neutral...”*

*Interview VI*

Once the specifying PBO has satisfied themselves that an NMS is likely to be appropriate for use on a project at a particular moment in the development process, the client and other coordinating PBOs engaged on the project will also need to determine whether the solution is acceptable to them (Section 8.5.3). This will entail undertaking an assessment of the anticipated impact on their project performance objectives of implementing the NMS, as well consideration of the impact on other decisions that have already been made. For example, subject to the timing of the proposal and the TRL of the NMS, the introduction of an NMS might result in the anticipation of additional work during implementation that might cause PBO performance objectives to be transgressed (Section 9.4.5). Data point D highlighted such a situation in which a structural engineer had progressed their initial designs on the assumption of the use of a dominant piling and foundation solution for a college project. An NMS was proposed by another PBO (at RIBA Stage 3) as an alternative, resource efficient, solution. The engineer refused to consider the NMS, indicating that the additional work – including technical validation – would take too long and cost too much, and that the proposed solution would deliver the performance objectives that had been established prior to their commencing work. Any desire for resource efficiency by other project actors was subjugated to the delivery of the engineer's host PBO's performance objectives relating to time and profitability. While not specifically articulated, this was considered to be the result of the potential for sanction for overstepping budgeted limits.

The impacts anticipated by coordinating PBOs from NMS implementation will be compared to the assumptions and decisions already made in relation to the project. If the specifying PBO has not recognised and incorporated the sanctionable performance objectives of coordinating PBOs into their specification decision, the proposed solution may sit outside of a coordinating PBO's solution space, and therefore be subject to resistance. This highlights the importance of extending a DMU's decision horizons to consider coordinating PBOs' performance objectives when attempting to introduce NMS to a project. For example, an architect that extends their decision horizons to consider contractor concerns of buildability into their design decisions may meet with fewer barriers than one who designs fantastic schemes that rely on 'sky hooks' – an imaginary structural engineering solution proposed in circumstances when designs preclude adequate internal support. This is, of course, heavily caveated by the fact that a client could well adopt the latter design decision as a project requirement.

As well as having established differing and potentially conflicting performance objectives, each of the coordinating PBOs may have different evidential thresholds for the use of products. Where a

coordinating PBO perceives an information deficit, they will also need to proceed through a process of information gathering / uncertainty reduction described in Figure 40 (shown separately as ‘invest II’ in Figure 29). This validation process will have time and cost implications for the coordinating PBOs. The extent to which they are willing to pursue evidence gathering or creation is influenced by the source and strength of the performance objective motivating NMS specification (Figure 35), the associated sanction for transgression, and the availability of time and budget in the PBO to undertake the search. Of course, proposals to implement an NMS may also threaten the delivery of a coordinating PBO’s performance objectives outwith time and cost. For example, the use of an NMS may have an impact on the habitat of the pygmy three-toed sloth. For clarity, however, the dominant objectives of time and cost are used for demonstration purposes.

While the preceding discussion has focused at the level of the PBO, it is important to recall that decisions are taken by individuals. The sanction for inappropriate decisions may be the loss of job, or status.

#### **9.4.5 Elaborating Impacts: NMS Implementation on Projects**

##### *The Influence of the Anticipation of Change on Implementation*

The implementation of an NMS on a project pre-supposes that it has successfully passed through earlier stages of the innovation adoption process, search, selection, acceptance and validation.

A large body of construction literature exists that explores the theme of elaborating change on construction projects. The lineage is typically traced back to Slaughter (1998, 2000) who developed Henderson & Clark’s (1990) work for the construction sector. In her 2000 paper, Slaughter distinguishes between innovations in construction based on two dimensions of change: ‘change in links’, reflecting the impacts that the introduction of a new technology has on other components or systems in the building; and ‘change in concept’, reflecting the amount of new learning that is required of a PBO to understand and implement the NMS. Both dimensions of change are explored further below. Slaughter (2000) unfortunately does not dwell on the impacts of the specification decisions other than to describe how the implementation of certain types of innovation will require the commitment from all of the affected parties, and depend upon some form of gain sharing. However, Slaughter’s analysis can be applied to explore the elaborating impacts of changes on the innovation process by creating a distinction between those NMS proposals that impact only the specifying PBO, and those that impact several (Harty, 2005; Sheffer, 2011). More recently, Levitt (2017, Non-participatory event BE) described his work with Taylor (2004) and Sheffer (2010) exploring this notion of elaboration more fully in the context of implementation.

##### *Change in Links Creating the Expectation of Elaborating Impacts*

Sheffer & Levitt (2010) adopt the metaphor of ‘swim lanes’ to explore the elaborating impacts of innovations on project participants’ construction activities. While they implicitly adopt the perspective

of the material producer, rather than a project focus, exploring how the rate of market diffusion of a particular technology might be accelerated, the lessons are instructive.

Where elaborating impacts from a specification decision impact only a single firm or discipline across life cycle phases, with no significant impact on other PBOs or disciplines, 'modular' innovations (Slaughter, 1998) changes are considered to occur within a single swim lane. Here, an individual PBO or discipline might be required to invest to advance an NMS to a sufficient TRL for implementation. To the PBOs in other swim lanes (disciplines), the solution ultimately presented for incorporation into the construction project is comparable (cf. Rogers, 1995) to the dominant solutions that have gone before, and they are able to continue their design and installation work as before. For example, the use of a new material in a window unit that otherwise has the same fittings, dimensions and fitting requirements can be installed as before without any need for new knowledge or training.

Sheffer & Levitt (2010) then compare these modular innovations with 'integral' innovations (Slaughter, 1998) that cross the 'swim lanes' of disciplines. Here Levitt (data point BE) provided the example of a fully pre-fabricated timber frame wall. The implementation of pre-fabricated walls requires change not only for the PBO creating wall panels, but also the patterns of work of the electrician, heating and plumbing engineers, designers, contractors and hauliers. The elaborating impacts of a proposal to implement such integral solutions will affect the implementation expectations of other PBOs, whose work and fee may be planned on the assumption of continuity. These impacts can be positive or negative. However, uncertainty over the impacts can lead to PBOs omitting consideration of the benefits to ensure that their performance objectives remaining unchallenged.

If the impacted PBOs are engaged prior to the specification decision to deliver a project using fully pre-fabricated walls, they will be able to assess the elaborating impacts, both costs and benefits, on their work. Where these elaborating impacts negatively impact established performance objectives, coordinating PBOs are likely to resist the specification proposal. Empirical studies suggest that modular innovations are more likely to penetrate the market than integral (Taylor and Levitt, 2004; Sheffer and Levitt, 2010; Sheffer, 2011). However, where the coordinating PBO's performance objectives have not been set, the decision can be factored into their establishment. If PBOs impacted by elaborating impacts do not have adequate resources available to accommodate the elaborating impacts, or indeed the motivation to do so, then the proposal to specify an NMS will be resisted.

Examples of the anticipation of these elaborating impacts were observed during the interviews in phase one of this study. Several interviewees described how the proposal to specify CLT on projects had been resisted by the quantity surveyor (QS) despite the overall cost impact of the implementation of CLT being shown to be cost neutral on projects (Jones, 2014). At the time of the study, CLT had a relative disadvantage in capital cost when compared to the dominant construction solutions of in-situ concrete and steel. However, it presented a relative advantage in (*inter alia*) time performance, reducing the time required to deliver the project, and hence, site costs. The resistance was described as resulting from the QS's elemental process of costing projects (Box 1, Section 8.6.3) in which the cost of materials is considered separately from the project site costs. The cost disadvantages of CLT

were compared to the dominant solutions. The elaborating impacts of the specification proposal would cause the QS's project performance objectives to be breached during implementation (Interview II). The other time savings were either ignored, or discounted. Interview II described how this resistance was overcome by convincing the client that the solution was both supportive of their non-financial performance objectives and cost neutral overall. Attaching the NMS to the delivery of the client's project requirements in this way led to the QS's assessment being set aside.

#### *Change in Concepts Creating the Expectation of Elaborating Impacts*

The relative stability of the construction sector has led to the institutionalisation of construction techniques, in particular in relation to structural solutions. For example, structural engineers and those that implement structural solutions in the UK are primarily taught how to design and build with concrete and steel. The institutionalisation of best practices in design codes and standards provide engineers with a way to address most situations efficiently. When confronted with the need for a new solution, the cumulative learning engineers and installers have undertaken relating to the dominant solutions may be of limited use. The new material may be conceptually different from the dominant solutions, with distinct advantages and disadvantages, and design requirements. That is, they must undertake learning “.. *about first becoming effective and then [...] how to be efficient...*” (Interview 3) in the use of an NMS. The learning requires developing both an understanding of the NMS itself (to allow validation and acceptance), and how to use it to build, and accommodate it in the proposed construction project (implementation).

‘Incremental’ innovations (Slaughter, 2000) are those that are conceptually comparable (cf. Rogers, 1995) with existing solutions (low change in concept), and so the additional learning required to implement them is typically low in both the specifying and coordinating PBOs. However, where the NMS are not comparable or compatible with existing solutions, the required costs of learning, re-skilling and coordination can fall on one or more project participants.

#### *The Elaborating Impacts of Developing the Necessary Skills and Knowledge to Implement NMS*

Interviews (2, 4, 5, II, VIII) highlighted how specifiers don't specify with complete knowledge of the NMS to be delivered on projects, but they will develop sufficient knowledge to be confident that the NMS could be implemented. Their knowledge and skills relating to the solution develop over the course of the project (“... *I didn't know what I was doing, frankly...*”, Interview II). Indeed, one site project manager described how his host PBO was confident that they could deliver a project with CLT, despite not having done so before:

*“...we obviously said we could do [it] ... it was all new to me [...]it was pretty much a stab in the dark.”*

*Interview VIII (Contractor)*

However, one of the key observations in phase one of the study, was that all of the interviewed actors expressed a confidence in their ability to get to grips with the technologies sufficiently to make a

success of implementation, typically with the help of sub-contractors. Their technological capability was not a limiting factor (Jones et al., 2016). As organisations develop knowledge of and experience with new technologies on the project ('learning by doing', Arrow, 1962), their perceptions of uncertainty, and the anticipation of transaction costs and time impacts of implementing those technologies fall.

Reinforcing the importance of considering both the technology and the context into which it is being implemented, Everett Rogers (1995) considers how innovation specification and implementation is more likely when the technology is:

- simple to understand and use, avoiding the need for significant learning time and costs;
- observable – the results of innovation are visible – that is there are established precedents of the innovation in use and the benefits case is clear. The opportunity for specifiers to see precedent studies is held out by many in the industry as providing comfort over the use of NMS. Where the technology is visible when in use, this provides even greater comfort. This reduces uncertainty, and reduces concerns over subsequent monitoring, remediation or litigation transaction costs; and
- trialable – that is, it can be experimented with on a limited basis, with reduced cost and risk implications. Innovations are easier to adopt if they can be tried out on a small scale (Interview II), on a temporary basis, or easily dispensed with after trial. Stepping away from construction, the notion of trialability can be seen, for example in the food market, where companies frequently give out free samples as testers. These are at no cost or risk to the consumer and can lead to adoption. It is challenging to see how free samples might be extended to the scale of a building project, in particular with materials that have structural features.



Figure 42 – The 'Pete Jump Test'. Simple, small scale testing to build confidence.

(Photo: Expedition Engineering. Reproduced with permission)

Products demonstrating these characteristics can provide potential specifiers with increased certainty over performance, reducing the anticipation of learning and testing time and costs in the NMS



specification decision. Where a solution is previously untested, or unused, the ability to trial the product on a limited scale, with limited downside risks, increases certainty of performance (for example, Jones, Martin and Winslow, 2017). If the solution can only be tested at full scale in situ, this precludes the opportunity to gain confidence in the solution for a limited outlay, adding significant risk to the project outcomes. Sometimes, simple small scale tests can be sufficient to gain client and PBO acceptance (Figure 42).

However, whatever the testing that has been undertaken during development the contractor must ultimately construct the building with the NMS, requiring a detailed knowledge of the NMS, its properties, and use in practice: the elaborating impacts may not fall hardest on the organisation making the specification proposal. This can require a significant investment in learning and training for the installer. Avoiding this cost is typically achieved by the appointment of specialist sub-contractors.

#### *The Role of the Sub-contractor in Reducing Elaborating Impacts of Implementation*

Sub-contracting is a typical response to, and result of, the fragmentation of mature industries. Organisations develop specialist knowledge in a product or service to serve a particular part of the industry. During the exploration of the use of CLT on projects, all of the interviewees described how delivery contractors employed specialist CLT sub-contractors to erect the building frame. These specialist subcontractors would be tasked with the detailed design and delivery of the CLT elements of the project. Such a use of sub-contractors obviates the need for extensive learning and training prior to project delivery by the contractor, reducing the anticipated impacts on transaction costs and time of developing sufficient certainty over the NMS in question. Indeed, the role of the management contractor today is more one of coordination of these specialist sub-contractors, reducing their need to develop such specialist technical knowledge. Further, sub-contractors are likely to be more willing to warranty their work, as they have a better understanding of the material's properties. This process of delegation allows risk to be allocated to the most suitable party to bear it, that is, with the best knowledge of needs for the proposed solution.

However, Giesekam et al. (2014) identified 'insufficiently developed supply chains' as a barrier to the uptake of lower embodied GHG materials, suggesting that there are not enough project actors with adequate knowledge of and skills in NMS deployment to allow the implementing organisation to address their lack of understanding. Indeed, NMS are niche solutions for small markets (Section 7.11), attracting few suppliers, and contractors are typically unwilling to use a solution for which there are limited number of suppliers due to the risks of hold-up (Section 7.8), or other abuse of their monopoly power (conversation with Associate Director Structural Engineer).

## **9.5 The Decision's Conditioning Structure: Endowments Supporting NMS Implementation**

### **9.5.1 Endowments: Resources Enabling Change**

The elaborating impacts from a proposed NMS specification can, therefore, impact on both the specifying and coordinating PBOs project objectives relating to time and cost by overturning prior

assumptions relating to the use of DMS on the project. These elaborating impacts arise in the search and selection, validation, acceptance and implementation phases of the innovation process and are, in part, a function of the maturity of the technology in question. The proposal to specify an NMS may also have elaborating impacts on the final built project that may not be welcomed by the client. Further, residual uncertainty influences the anticipation of policing and enforcement costs in the specification decision.

However, despite these elaborating impacts, NMS are still sometimes successfully implemented on projects. This suggests that the time and cost implications of the proposed NMS specification can be mitigated or accommodated by the endowments applied to the project at hand. The thesis now explores the endowments that facilitate implementation, comparing the recent literature exploring project endowments supportive to innovation using structural equation modelling (SEM) with the observed data.

### **9.5.2 Accommodating a Decision's Elaborating Impacts: The Role of Slack Resources**

*"When you're working in new materials, things go wrong..."*

*Data point 9*

Many of the elaborating impacts described above result from PBOs' unfamiliarity with the NMS being specified and uncertainty over the performance attributes of the NMS. Addressing this unfamiliarity requires an investment of time and financial resources. The availability of these resources will be dependent upon the timing of the specification proposal and the assumptions underpinning decisions on the allocation of resources to the project (Section 8.6.3). However, the competitive tendering process typically adopted in construction procurement ensures that the most cost and time effective proposals for delivering client requirements are awarded contracts. Therefore, the fewer resources applied to the project by the PBO, the higher the chances of winning contracts. Lean production techniques promote a tight coupling of delivery processes, creating value for the customer and reducing waste (Howell and Ballard, 1998; Lean Construction Institute, 2016) through the efficient delivery of the project. Indeed, interviewees described how they innovate in the delivery of their services to try and enhance their competitiveness and profitability (see also data point O), echoing the common discourse in the sector of productivity gain, improving the utilisation of cost and time resources (e.g. Farmer, 2016). This mitigates against the allocation of resources above the minimum necessary ('slack') to deliver a 'regime' response to the project performance objectives when proposing a fee.

*"... the amount of innovation we can have is limited by the procurement route and the competitive tendering that we usually have to enter into."*

*Data point 9 (Structural Engineer)*

In turn, this encourages PBOs to rely on tried and tested solutions (Barrett and Sexton, 2006) in delivering the project. Where the proposal for an NMS is made prior to a PBO's time and cost

performance objectives being established, the elaborating impacts can be factored in to these objectives. However, without such knowledge, bids will assume limited contingency over and above the costs indicated by a regime solution:

*“... main contractors operate on very small, 1 – 2 % margins, and actually, it’s still such a competitive market that we can’t really afford to be putting on much [contingency...]. You can’t say oh we’ll put 5% on the job. We won’t get it.”*

*Interview VI*

However, the availability of slack resources are considered to be critical in facilitating innovation. Nohria and Gulati (1996) argue that either too much or too little slack can be detrimental to innovation. This is borne out by Keegan and Turner (2002), who describe how innovation is unlikely in a resource constrained environment, but also that excessive slack leads to waste. The efficiency discourse, competitive tendering, tight coupling and waste reduction all stand in the way of the allocation of slack to projects to accommodate the elaborating impacts at the level of the PBO of a proposal to implement an NMS on a project. Studies exploring the role of slack in innovation typically focus at the overall organisational level (e.g. Bowen, 2002; Keegan and Turner, 2002; Sexton and Barrett, 2003a; Mumford, Bedell-Avers and Hunter, 2015), with little attention paid to the project commitments of resources made by PBOs and the associated PBO performance objectives. One notable exception identified during the research was a study by Bayer and Gann (2007) that identified the allocation of resources to a construction project as limiting on the PBO’s delivery on the project, and the subsequent implications for the PBO. However, the scope of this study was limited to the PBO, and so omitted consideration of the impacts of restricted resources on the delivery of project performance objectives and any associated sanction. When the proposal to specify an NMS is considered, all impacted PBOs should have sufficient slack committed to the project to address the elaborating impacts anticipated from the specification proposal. However, these slack financial resources will typically be funded by the client, re-emphasising the importance of the early project decisions. Where NMS implementation was not anticipated in the setting of PBO performance objectives, it is likely that the necessary slack will not be available, and proposals to implement an NMS will be rejected by coordinating PBOs unless they see value in other outcomes from NMS implementation.

An exception to this was observed in one project in which the client aspired to further improve the efficiency of delivery of a project after establishing a very challenging, constrained cost and time baseline. The project delivery team was instructed to seek out efficiency improvements that might provide the time and financial resources to explore other project improvements that the client sought. While an aspiration for innovation may create an appropriate context for implementation, it is no guarantee of success.

Those seeking to promote the use of NMS on construction projects should, therefore, consider:

- whether the NMS represents a modular or integral change.

- whether coordinating PBOs have established performance objectives at the point of proposal that may be breached by the elaborating impacts of NMS specification.
- whether each PBOs' project commitments of time and money at the point of proposal provide sufficient slack to address the elaborating impacts of NMS specification.

### **9.5.3 Accommodating a Decision's Elaborating Impacts: Which Endowments?**

#### **9.5.3.1 Endowments Enabling NMS Delivery**

Cost and time are clearly important in the construction project, with costs being the most commonly discussed project specific feature in the interviews. These characteristics tightly constrain decision-makers' solution spaces. Indeed, observations (for example, data points D, F, O, and AY) and interviews have confirmed the importance of these resources on NMS specification and implementation at a project and PBO level, Section 5.3.8. However, coding of the interviews undertaken in the research suggests that there are other endowments that might help address the elaborating impacts of NMS specification (Sections 5.3.3 to 5.3.6).

#### **9.5.3.2 Structural Equation Modelling (SEM) and the Resources Enabling Innovation Implementation**

Indeed, a recent turn in the construction innovation literature has seen the application of structural equation modelling (SEM) (Kline, 2016), regression analysis and factor analysis to the exploration of the pre-requisite conditions for implementation of novel techniques (Liu, Skibniewski and Wang, 2016; Ozorhon, Oral and Demirkesen, 2016; Olanipekun et al., 2017; Chan et al., 2018; Faried, Saad and Almarri, 2018). These SEM studies proceed as follows: following a review of the existing literature on a subject area, here sustainable innovation adoption (abstractions notwithstanding), surveys are undertaken of a defined population to assess the relative importance of the factors identified in the attainment of a particular objective. Hypothesised relationships between factors and outcomes are then studied to determine the most significant factors in delivering the desired outcome. The sample sizes required for reliable SEM results are very large, and many published studies, not solely in construction, are based on samples that are far too small (Kline, 2016). The use of such modelling is alluring, indeed, it was considered for this study. However, SEM studies provide only a partial insight to the circumstances that promote NMS specification and implementation on average, across a broad survey population and numerous projects. They provide little guidance as to how the specific, contingent circumstances of the project at hand can be analysed to influence NMS specification and implementation. Further, SEM studies are silent on the emergent nature of projects, assuming static conditions. Despite these limitations, these studies provide insight into the endowments that might influence the implementation of innovations through their extensive literature reviews.

Table 9-1 – Endowments promoting innovation implementation. Author's own analysis of relevant literature contributions

	Client's experience in innovation	Innovation / IP ownership	Time	Funds available	Facilities	Knowledge (management) and awareness	Supportive organisation culture	Trust and ongoing relationships	Experienced staff / labour	Confidence in NMS	Policy certainty	Leadership / Innovation Champion	Management commitment
Gieseckam et al. (2014)	✓		✓	✓		✓	✓	✓	✓	✓	✓		✓
Liu, Skibniewski & Wang (2016)	✓					✓	✓	✓	✓			✓	✓
Ozorhon, Oral & Demirkesen (2016)			✓	✓		✓	✓		✓	✓		✓	
Chuen Chan et al. (2017)			✓	✓	✓	✓		✓	✓	✓			✓
Febrina & Ekambaram (2017)	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	
Crossrail (2013)		✓		✓	✓	✓	✓					✓	

The important endowments identified in recent studies are summarised in Table 9-1 together with those highlighted in a review of sustainable innovation implementation papers from Febrina and Ekambaram (2017). The table also incorporates endowments identified from Gieseke et al.'s (2014) study of barriers to adoption of 'low carbon' materials. Such barriers are typically treated by researchers as ontological entities in their own right. However, they are considered here – in light of the critical realist position adopted – as evidence of some underlying deficit in motivation or capability (after Michie, van Stralen and West, 2011) reflecting an absence of a performance gap (opportunity), incentive (motivation), or necessary endowments (capability) supportive of NMS implementation. It is notable that there is a high degree of similarity between the endowments highlighted in the literature and those identified during the course of this study (Section 5.3). These endowments are now discussed in detail.

Febrina and Ekambaram also describe how authors typically use the descriptors 'enablers' and 'drivers' of innovation interchangeably (after Ozorhon et al., 2010). Clarifying the distinction they describe 'enablers' as the "*factors that can empower or facilitate innovation*" further distinguishing between "*resources for innovation*" (cf. endowments) or "*arrangements and strategies for innovation*" (cf. interventions). Drivers are described as "*the factors that cause and motivate innovation to happen*" (cf. performance objectives, performance gaps) (Febrina and Ekambaram, 2017). Jones et al. (2017, Appendix H) had concurrently reached a similar distinction, describing the need for both 'initiators' and 'enablers' to deliver change in construction (Figure 43).

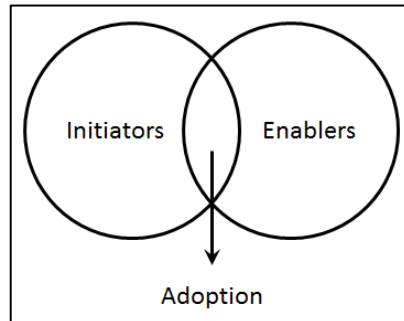


Figure 43 – The coincidence of initiators and enablers required to implement NMS on projects

These descriptions reinforce the distinctions between performance objectives and endowments developed here from the literature on structure and agency. It is unclear, and left unexplored by Febrina and Ekambaram, which, if any of the identified arrangements or strategies should be applied to deliver the desired innovation outcomes.

#### 9.5.3.3 Cultural or Physical Endowments?

Section 2.2.5.2 discusses the role of cultural and resource endowments in shaping the conditioning structure within which agency is exercised, that is, the decision-maker's solution space. Cultural endowments were described in Section 2.2.5.2 as:

*“... the intangible aspects of structure that relate to a decision-maker’s experiences, opportunities and outlook, incorporating historically contingent endowments in areas such as power and authority, economic system, position in a class structure, rights, legal context, and education and knowledge.”*

Reviewing the list of endowments supporting innovation implementation on construction projects in Table 5-1 and Table 9-1, the majority are seen to be cultural endowments, reflecting the attributes of the PBOs, or their team members. The only physical endowments identified are the resources of time, cost and the access to facilities for testing. However, the availability of facilities can also be ultimately reduced to questions of time and cost, as the testing required can readily be outsourced, at a cost, to specialist service providers. There may also be a time cost associated with that process resulting from scheduling and search (data point K).

#### *9.5.3.4 How do Cultural Endowments Influence the NMS Specification Decision?*

The influence of the cultural endowments can also be viewed through their impact on elaborating impacts, particularly on time and cost, of NMS implementation. While this perspective might be considered rather reductionist, the data and dominant discourses in construction supports such an analysis (Section 5.3.8, Table 5-2).

However, before exploring the various cultural endowments’ influence on time and cost, a specific category of endowment is considered, trust.

#### *The Role of Trust*

*“... unpredictability accompanies transformation, the willingness to proceed with a decision requires trust...”*

*Kane, 2013*

The review of endowments highlighted a client’s prior experience in innovation as supporting innovation implementation. This suggests that those clients that have experienced the process of innovation previously have developed an understanding of, and confidence in, the process of innovation, their in-house project team, and the external project team members, to deliver a successful outcome. This trust in the people and processes can promote a tolerance for ambiguity and uncertainty early in the development process. Trust has long been seen as a factor that is lacking in construction (Fellows and Liu, 2011, data point AT).

Trusting that the innovation process will satisfactorily resolve the uncertainty, given an appropriate application of endowments, may reduce the expectation of the monitoring and policing transaction costs that can be critical in decision-making relating to new materials (Qian, Chan and Khalid, 2015). The provision of additional investment of time or money when innovating, creating ‘slack’, reflects the value that clients attach to the performance objectives addressed by a proposed NMS. The role of trust on the construction innovation process and the anticipation of transaction costs would make for an interesting area of further study.

The literature suggests that prior experience in innovation enables further innovation. This stands in contrast to multiple observations in this study in which clients with no prior experience of building, let alone innovating in construction technologies, are willing to permit NMS specification on their projects. Reflecting on this, one interviewee suggested that this may be because:

*“Organisations which don’t build regularly have different risk attitudes to those that build frequently. Because they are already doing something that they perceive as risky, it is easier to sell them something different - because everything is new to them.”*

*Interview 3*

Such inexperienced clients are already entrusting their project to professional designers, to an extent they *delegate* decision-making authority (Section 8.4) to material specifiers, rather than simply seeking their advice, reserving few decisions for themselves. They extend this trust to the appropriate selection of certain materials. Clearly, where the client has a view on what a project should be constructed or finished with, they will express this as a form or project performance objective, either before a solution is proposed, or through the decision review process (Section 8.5.4).

The presence of trust, and the related professional reputation, allows project team members to anticipate the standards of performance expected from a specifying company, and this may increase their willingness to believe the specifier when they say that something will work (or not). Institutional rules, regulations and standards of performance provide a formal route to establishing a base level of confidence by describing minimum (pre-competitive) performance and behaviour standards, a so-called ‘level playing field’ (Morrow, 2013), but they do not address early uncertainty around NMS specification. Indeed, game theory describes how trust allows organisations to collaborate in repeat interactions, and reduces the anticipation of transaction costs (Morrow, 2013).

### *Knowledge and Experience*

The learning required to validate and implement NMS on a project is dependent on the DMU’s pre-existing stocks of knowledge at the point of specification. This, in turn, is dependent upon their prior experience and absorptive capacity, broadly, their openness to new ideas and information (Cohen and Levinthal, 1990). Project participants’ endowments of knowledge and awareness, and the availability to the project of experienced staff and labour represent the ‘stock’ of skills, knowledge and experience that are brought to a decision context (Section 7.4), influencing the conditioning structure of the decision-maker’s solution space. Where unanticipated learning needs to take place, this can impact on the project’s critical path, and cost profiles (data point AT).

Once a need for an NMS has been identified to address a performance need, the availability of these endowments to a project can reduce the elaborating impacts of the proposal for its



specification. For example, expectations of validation and monitoring elaborating impacts can be reduced through an awareness of or experience with the proposed solution. That same awareness ensures the solution appears in the DMU's solution space, reducing the impact of search. Implementation impacts can also be reduced where there are experienced and trained installers and established supply chains, reducing concerns over hold-up problems that arise from restricted numbers of suppliers.

#### *The Use of Knowledge Management Systems*

Knowledge management in construction is considered to be challenging, with site based workers developing tacit knowledge that is rarely captured and made available to the wider organisation (Styhre and Gluch, 2010). The failure to transfer knowledge between sites and projects means that the time and costs investments to address performance objectives may be duplicated across projects. Where organisations invest in knowledge management processes and technologies, cultural endowments of experience and understanding can be more readily shared, or accessed, increasing project-specific capability. This can reduce the elaborating time and costs impacts of investigating NMS on projects, reducing the anticipation of costs of search, selection and validation for project actors. However, such systems do little to influence the specifying or coordinating DMUs' motivations and opportunity to specify NMS on a project.

#### *Leadership and Commitment*

Much has been written on the role of the client in promoting innovation on construction projects, acting as both stimulus for, and leader of the innovation process (Blayse and Manley, 2004; Boyd and Chinyio, 2006; Brandon and Lu, 2009; Loosemore, 2015; Adams et al., 2017). Indeed, clients are well positioned to promote NMS specification through the articulation of performance objectives supportive of NMS implementation and their ability to sanction any PBOs that do not address their performance objectives. Leadership and commitment by the client may result in the availability of additional physical resources, providing the necessary slack to explore the NMS (Interview 5 refers, data points AS, BA), or incentives for PBOs to consider NMS (Interview 7). However, construction clients have rarely been seen to take the position of technical leader, or champion of an NMS, a role that typically falls to a senior member of the project team (Nam and Tatum, 1997) who also act as innovation process managers and boundary spanning object (Di Marco, Taylor and Alin, 2010). (*"It's [...] about understanding what the other members of the team are after..."*, Interview 5). This leadership role encourages the collaboration, effort and sacrifice necessary to identify solutions to address performance needs, and to limit the perceived elaborating impacts of NMS specification on other project members (Keast, 2006). The commitment and energy required from the role were frequently discussed in interview:

*"[It] felt like pushing a very large boulder up a very large hill. It's very exciting, but it's really hard work..."*

*Data point 9*

*“You’re more inclined to put the effort in to help people who want helping and appreciate your help and have the same [trails off]... they want make something happen.”*

*Interview 1*

The openness to risk and uncertainty, coupled with the client’s ability to command the resources and commitment of other project participants are typical characteristics of ‘innovation champions’ (Nam and Tatum, 1997; Jenssen and Jørgensen, 2004; Kulatunga, 2011) who encourage innovation implementation in project contexts.

#### *Supportive Organisational Culture*

The notion of culture is complex, and a detailed exploration of the concept is beyond the scope of this thesis. However, Liu and Fellows (2012) provide a concise summary of the main features of concern to construction professionals, describing how organisational cultures are initially established by the founders, shaped by the society in which they exist, and subsequently altered by other major stakeholders. These influences establish the norms and expectations within an organisation, permitting and sanctioning behaviours as appropriate (Simon, 1957). Over time, these behaviours can become institutionalised in rules and performance assessment systems, reinforcing (locking-in) the existing cultural features. When distinct organisations come together on a project, the individual organisations’ cultures combine to create a project culture (Liu and Fellows, 2012). In the project environment where PBOs may have conflicting cultures, it is typically the more powerful organisation’s culture that dominates (Furnham, 2012).

Reviewing earlier research, Liu and Fellows highlight the need for an organisation’s leadership to nurture and empower creativity (tolerance of failure, exploration and ‘slack’ resources), communication and feedback (an investment in learning and development), reward systems (motivating innovation) and innovation champions (see above). Together, these attributes can encourage risk taking and experimentation within organisations, but they each require the investment of resources by the organisation in longer term value creation. It is unsurprising that in the mature construction industry that competes largely on cost that slack is limited, and that research and development expenditure is low relative to other industries in the UK (BIS, 2013). Indeed, the openness to risk and uncertainty that is supportive of innovation is an anathema to many in the industry. One contractor described the impact of this resistance:

*“...if you start taking risks, the organisation’s immune system kicks in...”*

*Data point AT*

In this context the role of the client is reinforced:

*“The top tier contractors are the ones with the power [post-contract] and unless [the client] asks for these things, is aware of and asks for them, they won’t happen.”*

*Policy Stability and an Ability to Exploit the Innovation*

While strictly an endowment of the context, policy stability or certainty provides project actors with certainty over the future landscape in which they expect to operate. A stable policy landscape can increase their confidence (reduce uncertainty) that an investment will be recouped in the future (cf. data point AU). However, where the policy environment is shown to be uncertain or changeable, investment drops. The developments in sustainable construction materials and techniques brought about by the now withdrawn Code for Sustainable Homes is testament to both the power of regulation to provoke change, and the determination and power of those seeking to preserve the status quo. Anecdotal reports of investment decisions being postponed while the ramifications of the UK's vote to leave the EU support this. The position is summarised:

*“Uncertainty [...] carries a real cost. A consistent policy environment keeps investor risk low, reduces the cost of capital [...] and gives business the confidence to build [...] supply chains.”*

*Committee On Climate Change, 2018*

The ability to form confident expectations about the future operating environment is particularly important when investments in innovation are not immediately repaid by the project in which the investment is made. The client relies on the same stability to ensure that their costs are covered in the future. However, if the PBO is unable to recoup their investment on the project at hand, they must have confidence that they will be able to do so on future projects. If a PBO is confident that they will be able to re-use the learning and experience developed on a project, either through a long-term contract (the Anglian approach, discussed in Section 5.3.1), or through ownership of the intellectual property resulting from the investment, they may be more willing to invest some of their own endowments in the innovation process, rather than relying on client endowments.

In bespoke, one-off projects, the opportunities for consolidators – typically architects and contractors – to formalise ownership of the developed intellectual property is limited. This opportunity typically lies with the material suppliers who are at liberty to exploit the development on other projects. However, designers, contractors and sub-contractors are able to use the knowledge gained to achieve competitive advantage in future contracts.

*Relationships*

Interview 4 described the importance of relationships in winning work on projects:

*“[we won the work...] because of our relationship with [architect] on previous projects – one of the major reasons [they] wanted us on board is because we do a lot more than say ‘you can have this structure’...”*

Indeed, the ongoing relationship between the project sponsors and architectural practices led to their being engaged in several repeat collaborations. Architects appear to appreciate their commitment to design excellence and their ability to design intelligent, practical solutions to complex problems. Working on projects with architects develops trust (*q.v.*) and confidence in capability, as well as a mutual understanding of, and commitment to, performance objectives. Further, relationships can act as a form of boundary object, facilitating knowledge sharing and transfer both between project participants and from outside the project team (Gluch, Gustafsson and Thuvander, 2009; Styhre and Gluch, 2010), reducing the elaborating impacts of search and validation.

#### 9.5.3.5 Summary

This brief exploration of the endowments identified during this study has demonstrated that the cultural endowments identified as enabling NMS implementation on projects each influence, directly or indirectly, project participants' need to invest time or money in the innovation process. These endowments either ensure the availability of, or reduce the need for, the slack resources necessary to implement the NMS on a project.

As an example of the influence of elaborating impacts of proposals to specify NMS, Interview 8 explored the rejection of a proposal to use CLT on a project. The structural engineer was motivated to propose the specification of CLT because they valued embodied GHG efficiency, and perceived that the validation, acceptance implementation and monitoring elaborating impacts were relatively small due to the existence of experienced CLT sub-contractors. However, despite the opportunity to save money on the project for both client and PBO, the project manager was not interested in pursuing the specification proposal. They lacked the necessary knowledge and experience (endowments) to trust or confirm the structural engineer's assessment of elaborating impacts. Further, the project manager was not motivated by the need to save either embodied GHG or money, on the project.

*"[The project manager] might have spent half a million pounds more to do it in concrete. And that would have been fine. Because [...] they do a [financial] appraisal and if it comes in within that [...] appraisal, everyone's happy."*

*Interview 8*

However, the sanction faced by the project manager for failing to meet project objectives was considered to be too great ("*...his job was on the line if that project screwed up because of that decision...*", Interview 8). This highlights the importance of considering each of the levels of the project hierarchy when proposing NMS on projects.

## 9.6 Synthesis: Assessing the NMS Specification Decision

Figure 44, below, summarises the analysis of the NMS specification decision in light of the COM-B system of behavioural pre-conditions and the discussion in Chapter 8. It describes how the value drivers of project actors, represented in their performance objectives, can create

performance gaps or improvement trajectories, presenting specifiers with the opportunity and motivation to propose specifying an NMS on a project.

The proposal to specify NMS then creates the anticipation of elaborating impacts in decision-making to address information and performance deficits. That is, a perceived need arises – consciously or unconsciously – for the investment of additional time and money by impacted project actors in search and selection, validation, acceptance, implementation and policing and enforcement. The additional resources anticipated at the point of decision are a function of the maturity of the technology under consideration and can be mitigated by the existence and application of the cultural endowments of the specifying and coordinating DMUs. These elaborating impacts can be mitigated by the existence and application of cultural endowments. Physical resources of time and money, that is, slack, must also be available to address any residual elaborating impacts if the performance and information deficits of the NMS are to be addressed.

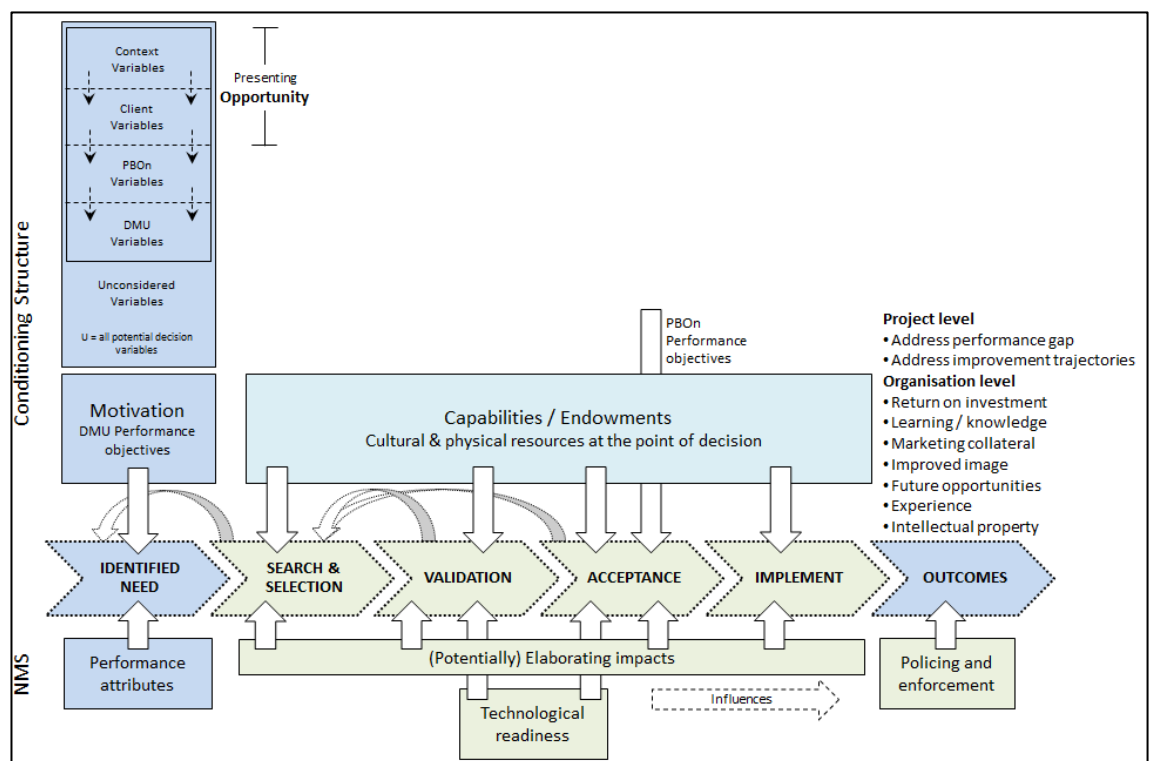


Figure 44 – Changing specification behaviour – capability, opportunity and motivations

Chapter 8 described how a project's resource availability and performance objectives are dependent, in part, on the timing of the specification decision. This same argument influences the emergence of performance gaps, creating the need for NMS on projects. Where the context or initiating client performance objectives create a clear performance gap, the resources necessary to accommodate the NMS can be made available by the client, having been incorporated into the early planning decisions. Indeed, several of the studied projects on which NMS implementation occurred were established with an anticipation of NMS implementation (including those reported in Gerrard et al., 2015; Jones, Martin and Winslow, 2017), and so an allowance of slack was incorporated into costings at an early stage. However, if no

sanctionable context or client performance gap exists supporting NMS implementation, a proposed NMS might be implemented if it addresses the project's time, cost and safety improvement trajectories (Section 9.3.1) without compromising project participants' sanctionable performance objectives.

Typically where proposals for NMS specification are made early in the project, fewer project and PBO performance objectives will be established, and an allowance can subsequently be made for the elaborating impacts arising from NMS specification on a project (Section 9.4 above) in actors' resource allocation decisions. Further, at the early stages of projects coordination is more straightforward, with fewer project participants with potentially conflicting project performance objectives and fixed endowments (Section 8.6.3). As project partners join the project later, early decisions are taken as project expectations and used as inputs to decisions as to the commitment of resources to the project, reinforcing observations that it is easier to influence NMS specification decisions early, rather than late in the project. In the surveys undertaken in phase one of the project, it was notable that all of successful implementations of CLT were proposed prior to contractor involvement, and typically proposed by the architect. Unfortunately, survey respondents were not asked the order of PBO appointment. The primary sources of resistance to the use of CLT was the quantity surveyor, due to the risk to the costs of delivery, which was also the primary reason for resistance. Later proposals to specify NMS may face rejection because the project's earlier decisions and the supporting assumptions of DMS use may preclude the NMS from the DMU's solution space. That is, of course, unless the NMS addresses a context or client performance objective that has emerged during the course of the project. In such a case, the client will need to assess the value that the objective brings and consider whether they are motivated to and capable of providing the additional resources necessary to address the emergent performance gap.

Section 8.5.4 describes how clients can adopt, formally or informally, the performance objectives recommended by their advisors. In successful implementations of NMS, advisor recommendations were observed as being adopted by the client as performance requirements or expectations, rather than aspirations. This constrained subsequent decision-makers influencing the process of coordination. Several Interviewees described the importance of this adoption process in ensuring that an NMS is not subsequently removed from the project, after its initial specification. For example,

*"If you really need something in the project [...] it has to be key to the design concept so that you can't take it out."*

*Interview IV*

Without this early client commitment to NMS implementation, a consensus must be formed within the project team as to the need for it.

*“...You have to have buy-in from the whole team. The QS and the main contractor in particular are critical to a successful project...”*

*Data point 9*

Interview II also described the importance of limiting other areas of change (*“Make one argument, and don’t do anything else. ... don’t do anything that’s going to require anything else that’s special”*) as this can create additional areas of uncertainty that require investment. The cumulative effect of uncertainty upon uncertainty can cause other PBOs – including the client – to resist change:

*“The client board felt that they’d [already] done their contribution towards innovation...”*

*Interview 5*

Applying insights from the behavioural sciences, DMUs are seen to be motivated to specify or accept NMS specifications in pursuit of their personal drivers of value. The opportunity to specify NMS is provided by an external decision context with supportive performance objectives. Case specific project endowments determine whether a DMU has the necessary capability to address the elaborating impacts on the adoption process caused by NMS specification.

## **9.7 Conclusion**

Chapter 8 introduced a new decision-based middle-range model of the construction project in which to locate a specification decision, and to understand its emergent conditioning structure. In doing so, Chapter 8 addressed three of the criteria for a model of the construction project identified in Chapter 6. Chapter 9 has now addressed the final criteria for a model by providing a means to assess the specification decision’s conditioning structure and its elaborating impacts. In doing so Chapter 9 has addressed objective 3 of this research.

Together, Chapters 8 and 9 describe a framework within which specification decisions can be located and assessed. This coordinated perspective of the specification decision and construction project now permits an exploration of the impacts of the interventions previously proposed in Chapter 6.

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## 10 Locating and Assessing Interventions to Promote Novel Material Solutions (NMS) Specification

*“Never tell people how to do things, tell them what to do and let them surprise you with their ingenuity”.*

*Patton, 1947*

### 10.1 Assessing Interventions to Overcome Lock-in and Promote Novel Material Solutions (NMS) Specification

The descriptive framework presented in Chapters 8 and 9 has provided a means of locating and assessing the NMS specification decision. This chapter now addresses Objective 4 of the research by assessing the ability of existing intervention strategies, introduced in Chapter 6, to promote NMS implementation on a project-by-project basis. Each intervention’s influence on a DMU’s capability, opportunity and motivations to specify NMS is described after a brief discussion, with reference to Figure 45, of how these concepts apply to the framework presented above.

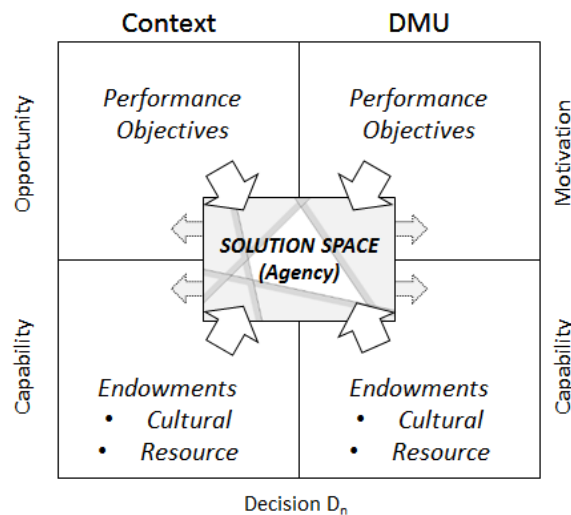


Figure 45 – The capability, opportunity and motivation to implement NMS

### 10.2 Behavioural Pre-conditions for NMS Specification – A Summary

#### 10.2.1 Opportunity: Presented by Performance Gaps

The opportunity for a PBO to successfully specify and implement an NMS is presented by the existence of supportive project context or client demonstrating sanctionable performance objectives that create a sanctionable performance gap. Without such an opportunity at the point of specification, a PBO that may be motivated to, and capable of, implementing the NMS onto a project will need to ensure that the proposal to specify an NMS addresses a client’s project aspirations. When addressing client project aspirations, the use of NMS should not risk the delivery of other client sanctionable performance expectations, established under the assumption of DMS use. That is, the NMS must perform at least as well as the dominant

solutions in terms of cost, time and health and safety. In effect, any “[*embodied GHG*] *benefits to the system need to be seen to be coming for free*” (Interview 1).

Where the client and context are silent on matters that are supportive of NMS specification, designers may still be able to create the opportunity to specify NMS by convincing clients that adopting an NMS supports other sanctionable performance objectives. If the client agrees, then the emergent project performance objectives can preclude the use of DMS.

#### **10.2.2 Motivation: Created by Personal/PBO Value Drivers**

The specifying DMU may be motivated to specify an NMS for a project if their own conceptions of value create a performance gap or improvement trajectory that is supportive of NMS specification, for example, a desire to address the embodied GHG of construction materials. The motivation to specify NMS might also be stimulated by the availability of client incentives that align with their other motivations, financial reward, recognition, or job security, for example.

However, both specifying and coordinating DMUs must be motivated to implement the NMS. Where a DMU proposal to implement NMS is adopted as a client requirement or expectation, NMS implementation becomes part of the successful delivery of client’s project performance objectives, and should motivate the coordinating DMUs. However, if the perceived performance gap remains at the level of the specifying DMU or PBOs, coordinating DMUs must be able to identify advantages that address their own value concerns if they are to consent to the use of NMS.

#### **10.2.3 Capability: Sufficiency of Endowments to Address Elaborating Impacts**

The capability to implement NMS on construction is a reflection of the need for endowments to address the elaborating impacts of the proposal to specify a particular NMS, and the availability of slack resources committed to the project to do so. These endowments relate to both the DMU and the broader project context

The need for slack is a reflection of the technology readiness (Appendix E) of the NMS in question, but can be mitigated by the presence of the cultural endowments described in Sections 5.3 and 9.5.3. The key determinants of the availability of adequate slack resources in PBOs and projects are considered to be the timing of the specification decision, actor value concerns, and the assumptions underpinning the commitment of resources. If insufficient slack is available in the specifying or coordinating PBOs to address information deficits, proposals to implement NMS will likely be resisted and barriers presented, unless the use of additional resources is sanctioned and reimbursed by the client.

In light of this summary, the following sections now consider how each of the interventions identified in Chapter 6 influence decision-makers’ solution spaces, addressing potential shortfalls in capability, opportunity or motivation to promote NMS on construction projects

## **10.3 Assessing, and Locating Interventions**

### **10.3.1 Education and Information Interventions to Populate or Amend the Solution Space**

Interventions promoting the provision of education, information and training seek to address capability and motivational deficits (Michie, van Stralen and West, 2011).

#### *Impact on Motivation*

The motivation of project actors to specify an NMS can be increased if they understand how the advantages of an NMS align with their drivers of value, be they the pursuit of opportunity, or the avoidance of loss (Appendix A). This understanding can lead to the introduction of new performance requirements or expectations at client, PBO or DMU level, influencing the specifying DMU's solution space. Indeed, many organisations have attempted to re-frame sustainability by aligning the delivery of sustainable projects with enhanced financial value, a typical business driver. Motivating specifying DMUs in this way can create a demand for NMS at the specifier level. However, it is only where the new performance objectives arise at the client level that their motivations manifest in project performance gaps providing specifiers the opportunity to specify NMS. As has been described, it is the upper levels of the project hierarchy that have the more significant impact on the opportunity for project actors to specify NMS. For example, the UK's Green Building Council (UKGBC, 2018) reports on the business (i.e. short and long-term financial) value that 'sustainability' can bring to those in the industry. However, there is typically a focus on those metrics that deliver measurable, short-term value improvements to the organisation. It is notable that the UKGBC report offers little to assist decision-makers increase an organisation's resilience by addressing the long-term risks presented by the need to move towards a low embodied GHG built environment.

#### *Impact on Capability*

Capability can also be enhanced through the provision of technical information and training, reducing information and skill deficits. In turn, this reduces the elaborating impacts of the NMS adoption process resulting from search, validation, acceptance, implementation, or policing and enforcement. The need for slack endowments on projects is thereby reduced, matching more closely the assumptions of DMS use. It is clear that if someone knows how to do something, they don't need to expend resources (time, money) to learn about it. Information can either be provided in advance of the specification (marketing) to increase awareness and ensuring the solution's appearance in the DMU's solution space, or as a response to a specification proposal, through databases, for example (Peat, 2009). Technical information should be available to the specifying DMU in a format that allows for straightforward assimilation into processes, for example, through BIM objects, or Excel files. However, the cost of producing this information remains significant and non-project level interventions may be appropriate to address these barriers to data provision. The costs of database solutions that improve the

efficiency of search can be prohibitive for smaller practices, negating the benefits of search efficiency.

Education and training interventions therefore have two distinct roles: to enhance actors' motivation to establish supportive performance objectives that create a performance gap, and to reduce the impacts of implementation by addressing information deficits. These roles are both important, but not sufficient to motivate the whole project team to implement NMS on a project. However, the creation or identification of client performance gaps is considered to be both necessary and sufficient to create the opportunity and motivation to do so.

However, the information that is required to create these client performance gaps is not related to the NMS itself, a supply side intervention, but rather relates to the need for the NMS, a demand-side stimulus. The information presented to clients must, therefore, make a strong value-based case for the use of NMS on construction projects. Information, education and training efforts should be directed at enhancing client awareness of the value impacts, both risk and opportunity, of specifying low embodied GHG materials. In keeping with the discussion in Chapter 8, this process of client education must occur prior to the fixing of endowment commitments to the project by the client on a project. A failure to incorporate assumptions relating to the use of NMS on projects in early decisions will result in the default 'regime' assumption of the use of a DMS. Where non-client PBOs have established project resource commitments prior to the identification of the performance objective requiring an NMS, additional resources can be made available through change control processes.

The specific information, training and skills-based interventions identified in Chan et al. (2017) are now considered for their suitability for use at a project level in light of this analysis.

#### *Creating Opportunity? Public Environmental Awareness - More Publicity through Media*

These interventions aim to increase the public's level of awareness and understanding of the issues surrounding the use of low embodied GHG materials. This can influence the context performance objectives, shaping the contextual demand for NMS. The intervention may be effective if embodied GHG becomes a salient issue to the public or market place. This market concern may then influence developers' social license to operate if they use high embodied GHG materials (Provasnek, Sentic and Schmid, 2017). However, such changes in the landscape occur slowly (Section 7.11).

From the perspective of the individual project, therefore, these interventions are likely to be ineffective, unless media campaigns relate to the impacts of the specific project itself, as happens on larger infrastructure projects, for example. In such cases, impacted external project stakeholders may be motivated to engage with the project to influence decision-making at the client level to protect their own performance objectives for the project.

### *Creating Opportunity? Educational Programmes for Developers, Contractors, and Policy Makers*

Education programmes for this group of actors is more directly applicable to the project context, increasing the likelihood of performance objectives being established supporting NMS implementation. However, the education programmes must focus clearly on the drivers of value for the respective actors, be that the avoidance of risk, or the seizing of opportunities. Each group must, therefore, be considered individually.

Educating policy makers may, in time, lead to regulatory change. However, aside from infrastructure projects, regulatory change can take more time than is typically available to individual projects. Contractors, as powerful systems consolidators and PBOs would also benefit from an awareness and understanding of the problems of climate change and the solutions available to address it on projects. This can create a motivation to promote NMS at the level of the PBO. Similarly, reducing the costs of search and selection with appropriate education can also enhance capability .

Educating developers (clients), however, can present an opportunity to create performance gaps on projects. This insight is a key finding from the analysis made possible by a morphogenetic consideration of the nested project environment. However, the timing of this intervention is critical (Section 10.4 below).

### *Enhancing Capability and Motivation through Better Research and Communication*

Increasing research and the subsequent communication of results relating to NMS helps to enhance the perceived technology readiness levels (Appendix E) of a material, and can address information deficits reducing the need for slack endowments on projects. While this is welcome in enhancing capability, it does little to address the motivation or opportunity to specify NMS.

Research at the level of the individual project takes place during the innovation process at the validation or acceptance stages, requiring investment of resources. In this way, clients can influence subsequent projects' specification decisions by enhancing the information available about the NMS in question. Indeed, this is the underpinning strategy for those recommending that government procurement policies be adapted to promote NMS.

### *Competent and Proactive Green Building Technologies Promotion Teams / Local Authorities*

This intervention description from Chan et al. (2017) can now be seen to create an inappropriate equivalence between the demand and supply sides of the NMS specification decision. A competent and proactive local authority is in the position to create a performance gap on a project, motivating a demand for NMS. However proactive they may be, local authorities may still lack the motivation or opportunity to implement such rules, for example, due to constraints at the national level.

Those promoting NMS, typically suppliers or PBOs, can create these motivating performance gaps by convincing project actors, in particular clients, of the importance and short and long-

term value of the relative advantages of their particular offering. If those relative advantages are not valued in the project context, there will be no opportunity or motivation to specify the NMS. As noted above, awareness and understanding can be enhanced ensuring that the solutions appear in the decision-maker's solution space, reducing search costs, and enhancing capability.

#### *Enhancing Capability and Motivation through the Provision of Better Information on Cost and Benefits*

The strategy of providing 'better' (more, reliable) information on costs and benefits of an NMS to clients and specifiers is presumed to address information deficits enhancing perceptions of technology readiness. Where project actors already have the opportunity, and are motivated to specify NMS, the provision of additional information will reduce search and validation impacts of the specification, increasing the likelihood of the NMS appearing in the DMU's constrained solution space.

Further, the availability of information on benefits can be helpful in creating a performance gap that an NMS can address, but again relies on the benefits being valued in the project context to motivate appropriate client or specifier behaviour. There is little to be gained by extolling the embodied GHG virtues of rammed earth if the client does not see value in lowering the embodied impacts of their project, or has concerns over the duration of the project.

#### **10.3.2 Motivating Implementation: Improving the Cost / Benefit Ratio of Adoption**

Decisions to implement NMS on construction projects are, effectively, a form of cost benefit analysis (e.g. data point M, Appendix A) in which the financial and non-financial benefits of adoption are weighed in the context of the performance objectives and endowments shaping the decision-maker's solution space. Either reducing costs or enhancing the benefits can increase the perceived value of the project (Mills, 2013) and can motivate behaviour change.

Chan et al., (2017) identify two interventions that enhance the cost/benefit ratio of adoption: financial and market-based incentives, and low-cost loans and subsidy from government. Together these are intended to mitigate against the risks to projects' financial performance objectives from specifying NMS, introducing a source of financial slack to address the elaborating impacts of the specification across validation, acceptance, implementation and policing. Data point F provides an example of when an embodied GHG reduction project was only initiated when funding was provided externally. An alternative means of favouring NMS is to discourage the use of the dominant solutions through some form of GHG or resource levy that reflects their detrimental impact on society (externalities), removing them from a DMS defined solution space.

While the provision of financial support enhances the capability of project actors to incorporate the NMS into the project, the provision of financial incentives is unlikely to address a lack of opportunity or motivation to specify unless they are at such a scale that the elaborating impacts

of specification are more than compensated for, and the relative advantages of the NMS becomes one of cost, valued by most clients. Similarly, the availability of low cost finance may induce material producers to invest in new technologies that might not otherwise be considered. Such low cost loans loosen the selection criteria of the regime (Section 7.11) by requiring a lower rate of financial return from an investment in NMS, recognising the niche nature of the market.

Febrina and Ekambaram (2017) also discuss interventions promoting green building technologies that shift the business case, in particular by exploring the entire project life cycle, or the potential for repetition. The latter strategy has been discussed in Section 9.5.3.4 describing how repeated implementation of an NMS allows for the recovery of investments made in the initial adoption process, and the creation of temporary competitive advantages. Life cycle costing encourages decision-makers to assess the cost performance of constructed assets over its entire life (BSI, 2008). It is considered to de-emphasise capital costs in decision-making, promoting design decisions that may lead to a higher capital cost, but result in lower running and business costs, such as increased levels of insulation. Indeed, BREEAM gives projects credits for the use of life cycle costing. However, while the use of bio-based, low embodied GHG materials is considered to improve indoor air quality (a potential improvement trajectory), and hence staff welfare costs, a reduction in embodied GHG in the initial construction is in itself unlikely to be linked to significant building life cycle savings. An exception to this might arise where the use of low embodied GHG building elements can be shown to lead to cost savings during the replacement cycle in a resource constrained future. However, this has not been viewed in practice during the research. Therefore, the use of life cycle costing would fail as a motivating strategy to promote the use of NMS, unless the NMS had other relative advantages that promoted operational savings.

#### *Motivating Implementation: Expanding Project Benefits by Adopting NMS*

The benefits of NMS use are not explored at any length by Chan et al., other than by describing the importance of having clear information of the benefits to aid decision-makers. However, it is important to mention the literature (Table 5-3) relating to value management in the context of benefits. During the research, external project stakeholder value perceptions were observed to influence the creation of client performance objectives and performance gaps on projects, re-shaping the DMU's specification decision solution space to include NMS. Consulting external stakeholders can, therefore, lead to circumstances in which NMS implementation can increase wider stakeholder value, addressing performance gaps and potentially enhancing client satisfaction. However, the timing of such consultations is important, it should begin early, and be a process that continues throughout project development (cf. Cabinet Office, 2013). Consulting early ensures that wider stakeholder conceptions of value can be incorporated into the development of project objectives, framing early decisions, such as budget. This ensures there are sufficient project endowments available to address any elaborating impacts from proposals to implement NMS to satisfy stakeholder requirements. Where stakeholder

consultations are postponed until budgets and time lines have been fixed, changes reflecting stakeholder value concerns may threaten financial and time performance objectives of both project and project PBOs, and risk rejection.

It is notable that many of the projects identified as successfully implementing NMS during the course of the research were not created for traditional property developers, but were largely privately funded projects, reducing the influence of external financial stakeholders and the influence of debt servicing. To reduce this reliance, one developer had arranged their business such that rather than outright purchase of land, they had taken out options on land. This meant that they didn't have to pay for the land they use until they sell the building they're putting on it. They were able to do this because they were promoting NMS that supported the municipal landowner's performance objectives.

### ***10.3.3 Creating Opportunities? A Supportive Regulatory Context***

The importance of a stable regulatory context for NMS specification has been discussed in Section 9.5.3.4. However, the strategies discussed by Chan et al. (2017) also suggest the need for regulations that actively promote the use of NMS on projects.

*Mandatory Governmental Policies and Regulations /  
Government Regulations That Encourage Innovation /  
Availability of Institutional Framework for Effective Implementation of GBTs*

These three interventions are discussed together as they reflect similar preoccupations with the performance objectives of the context in which development takes place, shaping project responses. In particular, mandatory policies and regulations represent contextual performance requirements, the strongest form of performance objective or performance gap shaping the DMU's solution space. Failure to address these performance requirements can lead to sanction, and ultimately no building. Establishing national policies that promote the relative advantages of NMS over those of the DMS is likely to create performance gaps for any development project in the country. The increasingly challenging performance requirements of the UK's Part L Building Regulations provide an example of how mandatory regulation can be used to incrementally enhance performance, amending designer and construction behaviour. The availability of these strategies as interventions on specific projects is, of course, limited.

However, this highlights the importance of the form of both regulation and specification by clients. Where specific solutions are prescribed by regulation or client, the opportunity to specify NMS is lost. Similarly, proscriptive historical regulations can preclude the use of NMS because they do not accommodate new technologies. Where buildings are described in terms of the performances that must be achieved ('what to do'), rather than by how to achieve a performance, designers and builders have the flexibility to identify solutions to deliver these performances (Aidt, Jia and Low, 2017). The point is made in the context of construction:



*“The challenges and risks for the project-based firm escalate as clients pull away from specifying what they want in detail. But the opportunities [to innovate] also rise dramatically, and especially in terms of how innovative these firms can be.”*

*Keegan and Turner, 2002*

Government regulations incentivising innovation can also take the form of direct support for actors developing NMS in pursuit of government goals, for example, via Innovate UK, or the use of procurement strategies in their own estate that establish performance gaps to be met by NMS. As discussed above, interventions promoting the imposition of new regulation and the provision of government support are not typically available as an intervention to project actors, notwithstanding that they can take advantage of them when they arise.

The discussion on institutions in Chan et al., (2017) stems from a number of papers that explore the broader socio / political / economic contexts of development, including the economic system in which the development takes place (e.g. Bondareva, 2005). Bondareva's exploration of LEED implementation in post-communist Russia re-emphasises the importance of considering the broader contexts in which the construction project is located when considering interventions. Decision drivers can differ dramatically by country, and interventions should take account of local differences. Indeed, during the research, industry actors frequently pointed towards other northern European countries (Germany, Sweden, and the Netherlands) as exemplars for sustainable innovation. However, the socio / political / economic environments in these countries differ significantly from that in the UK, influencing decisions on projects.

#### *Better Enforcement of Existing Green Building Policies and Standards*

This strategy sits outside of the project domain making it unavailable to project actors. In effect the enforcement strategy calls for the imposition of sanctions against those projects that fail to adhere to existing building codes, regulations and planning conditions. In the UK, it is incumbent upon the project team to design and deliver a building to meet the necessary standards and regulations. The process is typically monitored by planning authorities and building control. If project actors were found to be routinely flouting regulations, they may soon develop a negative reputation, reducing client and PBO trust. However, the challenges in this area are already apparent in the debate over the 'performance gap' between the energy use in buildings as designed and as built (Committee On Climate Change, 2018).

#### **10.3.4 Motivating Implementation? Green Rating and Labelling Schemes**

Sustainability rating and labelling schemes, such as BREEAM, can be mandated by regulatory authorities (context requirement), or adopted by clients in response to a perceived market demand, or in pursuit of competitive advantage (client requirement). Such rating and labelling schemes *can* introduce higher level project performance objectives creating the opportunity to specify NMS by restricting decision-makers' ability to specify DMS. While it is not in the gift of project teams to unilaterally adopt these rating schemes for projects, they may use them – or their own similar schemes (Interview VII) – to guide their design decisions (DMU/PBO

performance aspiration), motivated by the need to enhance the sustainability of their projects. Only when a client is required to, or elects to, adopt the schemes can they be used to establish project performance gaps, and the opportunity to specify NMS. Indeed, the limited uptake of the UK's Home Quality Mark highlights how most home builders will only adopt rating schemes when required to do so – the (context) demand for these rating schemes from house buyers is not sufficiently strong, or organised. However, the question of capability to deliver NMS in these circumstances still turns on the availability of endowments to address any information deficits and record keeping requirements.

Notwithstanding their limitations, when applied consistently, these rating and labelling schemes have the ability to slowly increase performance standards within the industry (data point AA), promoting new baseline performances for certification. Organisations that perceive value in sustainable construction techniques will seek to achieve the highest ratings, creating a (niche) market demand for NMS, and triggering the creation of data to address information deficits that are slowing uptake. As the market responds to this demand, these new solutions will become increasingly visible, and more data will be available on their performances, increasing certainty and reducing the elaborating costs of validation, acceptance and monitoring for others in the market that may place less value on sustainable outcomes.

### ***10.3.5 Enhancing Capability, Creating Opportunity? Promoting Project Integration***

A number of intervention strategies have been proposed that encourage the re-integration (or de-fragmentation) of project teams including project integration (through supply chain integration or Integrated Project Delivery), collaboration of skills and experience and the pooling of gains and losses (partnering) (Nam and Tatum, 1992; Dulaimi et al., 2002; Sheffer, 2011; Wamelink and Heintz, 2015; Febrina and Ekambaram, 2017). These strategies each reflect the project decisions around the appointment and coordination of project participants by the client or their representatives. This collaboration and integration has several influences on the project participants' capabilities. First, by pooling the experiences and knowledge of project participants at the point of initial specification, a DMU's solution space will be more clearly defined by the requirements of all project participants – extending the DMU's decision horizons – and will be populated by a larger number of potential solutions based on the experiences of other project actors (data point I). Together these reduce the elaborating impacts of search and selection, validation, acceptance and potentially implementation and policing. Knowledge can be more readily transferred between project actors, and boundaries between organisations can be reduced.

As has been described, early formalised and sanctionable project decisions have a strong influence on the availability of endowments to overcome the early assumption of the use of DMS on a project. If project actors promoting NMS are involved in those early decisions, they may be able to influence the client's decision-making on early project performance objectives, and hence inform subsequent project decisions. However, the decision to adopt project

integration techniques typically arises after a number of key establishing decisions have already been made, including, typically, the budget. Therefore, while the integration of project teams may motivate project participants to make decisions on the basis of what is 'best for the project', thereby maximising their own returns, the opportunity to do so will only arise if the client values, and makes support for NMS explicit in the project's founding assumptions (after Hardie, 2011).

### ***10.3.6 The Exercise of Agency: Improving Decision-making***

Chapter 6 explored several approaches to improve decision-making to support the integration of sustainable technologies onto construction projects. The impacts of each intervention to improve decision-making on the capability, opportunity and motivation to specify NMS are considered below.

#### *Optimising Rather than Satisficing*

The use of decision support tools, in particular when associated with material databases, can improve the efficiency and effectiveness of search and selection. The associated availability of material information and precedents can also reduce the costs of validation, acceptance and post-installation monitoring. The anticipation of elaborating impacts and the need for slack arising from the specification decision can be moderated. However, these savings can be counteracted by the time necessary to establish client preferences between each of the myriad performance attributes of the materials under consideration. As described in Section 2.1.1 for suitable comparisons to be made, the degree of abstraction must be reduced to a minimum, leading to the comparison of many attributes. Comparing an abstraction, 'sustainability', with a non-abstraction such as 'capital cost' presents challenges. The AHP (Saaty, 1990), for example, requires a comprehensive 'pair-wise' comparison of preferences between performance attributes to establish preference order among performance attributes by an individual that can be used to weight decisions. These preferences must then be moderated: a balance must be sought between the performance objectives (motivations) of the project actors and stakeholders influencing each specification decision.

Interventions to improve decision-making are typically silent on the opportunities to specify NMS. There is no guarantee that a DMU's solution space will be defined to contain an NMS, nor that the NMS will be selected if other less novel solutions are available. Again, the timing of these interventions supporting the specification decision means that it is likely that many project performance objectives will already have been established, limiting the endowments available to accommodate any elaborating impacts from the specification.

#### *Ensuring that NMS are Considered*

The inclusion of NMS into decision support tools means that they will form part of the set of solutions that are considered for a project. However, whether these solutions appear in the feasible solution space for consideration for a project will be determined by the conditioning structure of the decision formed by the performance objectives established prior to the

specification decision (Watson, 2015, provides examples). This intervention addresses a part of a DMU's capability requirements, awareness, but does not influence their motivations, or the need for any additional endowments resulting from the selection of an NMS in the specifying or coordinating PBOs. Further, the consideration of NMS by a specifying PBO has no influence on the performance objectives of the context or client that provide the opportunity to specify NMS on projects.

#### *Requiring or Encouraging the Use of New Decision Variables*

Strategies to ensure that decision variables supportive of low embodied GHG materials are incorporated into decision-making can certainly influence the search and selection processes of the specifying DMU. They have the potential to create a performance gap, and hence an opportunity to specify an NMS. However, the location of the performance gap so established in the Need Location Matrix (Figure 35) is important in determining whether the NMS is specified and subsequently implemented. For a proposal for NMS specification to succeed, each coordinating PBO must also recognise and adopt the relevant decision variables, that is, they must be similarly motivated to constrain their decision-making. Solution spaces can be aligned through the reward structure or procurement method. If a performance requirement to consider a new decision variable is established or adopted by the client, then the opportunity to specify an NMS is presented (Interviews II and 3 provided examples of clients adopting supportive positions encouraging NMS specification and implementation). However, without client adoption of the relevant decision variable, or adequate enabling resources, the elaborating impacts of NMS specification will likely cause its rejection.

#### **10.4 Creating Opportunities to Specify NMS on a Project-by-Project Basis**

*"...it's all about identifying and mobilising value..."*

*Interview 3*

The construction industry can and does innovate in material use. A challenge in this thesis has been to identify circumstances in which project actor motivations have been aligned, overcoming industry fragmentation. Regulators and clients are well placed to create the alignment necessary given their location in the project hierarchy. However, there is little short-term motivation for them to encourage the use of low embodied GHG NMS on projects. This removes the opportunity for motivated project actors to implement them. Before discussing how these project actors might identify opportunities to specify and implement NMS on individual projects, this section describes the broad strategies that have been observed to support successful NMS specification and implementation on projects.

Each of the projects observed on which NMS have been implemented has addressed one or more of the following strategies, influencing specifiers' opportunities to specify an NMS:

- A) NMS specification has been used to address project requirements and expectations that are imposed upon the client by the project (PESTLE) context or site conditions. Indeed,

where problems arise on site, the need to deliver the building to the client's performance objectives also leads to creative problem solving that may support the use of NMS.

- B) The use of an NMS has enhanced the delivery of the project participants' improvement trajectories, typically leading to faster, cheaper, or safer project delivery or operation. That is, a business case for the NMS has been made.
- C) The PBO or DMU has influenced the project's performance requirements and expectations by responding to the client's conceptions of value. For example, by the articulation of the reputational benefits of a particular design feature that can only be met by an NMS. Typically this route has been successful where project resource budgets have not yet been fixed.

This summary, developed from a review of projects in the research data, echo the analysis by Lim & Ofori (2007) who, adopting an Australian contractor's (PBO) perspective, also identify three categories of innovation: innovations that the client will pay for (strategies A/C), those that reduce costs for the contractor (strategy B, excludes time and safety drivers) and those that address the contractor's non-financial performance objectives, such as reputation (strategy C).

Strategy A here creates a shift in demand for NMS on projects, influenced by regulation, the market, or the project context, each of which may shape a decision-maker's solution space to preclude the use of DMS. If this demand is not addressed, the project may be considered a failure. While this intervention is not directly available to project participants, it is worth reviewing whether a passive niche has been formed by the project's contextual conditions that might be supportive of NMS specification.

However, in the majority of cases observed, the implementation of an NMS was successful because it had a net-positive effect on time or cost improvement trajectories (B), and/or the NMS had been proposed to address other client performance objectives (value drivers), and cost and time expectations had not been fixed assuming the use of DMS at the point of specification (C). Where financial value is to be found in the adoption of sustainable construction techniques in the short to medium term (B), NMS will, subject to the eradication of information and performance deficits, be readily adopted by the market. This is evident in the diffusion of CLT across projects in the UK. However, many other NMS do not provide this time based competitive advantage, and suffer from excessive performance uncertainty.

Strategy C describes the situations where the opportunity to specify an NMS was presented by the client's perceptions of value, and/or project endowments were available to address the elaborating impacts of the specification proposal. That is, the client's decision horizons extend beyond those of the 'regime' to incorporate additional decision variables, creating a performance gap and providing the opportunity to specify NMS. If a DMU can demonstrate that the use of an NMS addresses a client's notions of value, cost and time increases beyond the project performance expectation may be considered acceptable to the client (e.g. Interview 2; data point AZ; Soetanto, Glass, et al., 2007). They may be willing to invest on a project to

capture that additional value, creating sufficient slack to address the elaborating impacts of NMS specification and implementation. However, the timing of this value argument has been shown to be critical (Chapters 8 and 9). Proposing the use of an NMS early in the project limits the risks that other sanctionable decisions may preclude implementation. Further, ensuring that the use of an NMS is linked to the delivery of client or context performance requirements or expectations increases the chances that subsequent decision-makers will remain bound by the specification. Addressing a client's value requirements for a project can, therefore, shift the basis of procurement from a financial based decision-making process to one that is value-based, re-shaping the DMU's solution space. Value-based arguments are more likely to be successful where an organisation's senior stakeholders are committed to the project performance objectives addressed (Section 8.3.2.3, data point AC), however, they require clients to be able to articulate these drivers of value early in the project. This is not always possible.

This focus on the client (Section 5.3.1) is consistent with recent studies highlighting the relative importance of 'company requirements' and 'company related drivers' in promoting the implementation of Green Building Technologies (Ozorhon and Oral, 2017; Darko et al., 2018) in the Turkish and Ghanaian industries respectively. The framework presented in this thesis helps to understand *why* this is the case. Those wishing to promote the use of NMS on projects should review the project conditions at the point of specification to identify where performance gaps exist.

The Need Location Matrix (Section 9.3.4) provides a framework that can be used in conjunction with tools describing value drivers on projects (for example the Spencer & Winch, 2002, Mills, 2013, or GRI, 2014) to identify and locate a project's sanctionable performance objectives, performance gaps and improvement trajectories supportive of NMS implementation. However, due to the contingent nature of the project and client perceptions of value, this search may not identify a performance gap directly requiring a low embodied GHG NMS. It may, however, highlight opportunities to innovate in other areas of the project to add value to the client and advance other DMU performance objectives. Specifiers should be flexible and creative in their attempts at innovation, aligning the relative advantages of an NMS with the project performance gaps.

One-off clients may only be concerned with the value generated by the project at hand. However, repeat clients may be motivated to invest in addressing longer term value creation in pursuit of competitive advantages. Medium term value creation opportunities such as marketing and learning may readily attract investment, however, clients appear to not yet perceive the value of investing to address longer term transition risks resulting from the Paris Agreement and Climate Change Act. Engaging clients with these risks may lead to their having the motivation to invest in NMS implementation.

## 10.5 Creating Performance Gaps: Deriving Value from the Avoidance of Transition Risk<sup>12</sup>

If the UK is to deliver on its commitments to the Paris Agreement and the requirements of the Climate Change Act, the GHG embodied in new buildings must fall. However, if NMS with a sufficient level of technology readiness are unavailable by 2050, repeat builders will be unable to build at today's scale, impacting market returns. Further, if re-fitting buildings depends upon the use of high embodied GHG materials, this process may become unviable. In other words, if a significant reduction in output volume or increased costs is to be avoided, low embodied GHG NMS must be adopted on projects delivered in a low- or net-zero GHG world. However, the necessary technological innovation and diffusion processes are likely to take too long under a business-as-usual scenario in construction, requiring a cost-averse, conservative industry to mobilise in the short term (Giesekeam, Barrett and Taylor, 2016; Lehne and Preston, 2018). Without short-term action to promote their use on projects, NMS are unlikely to have had their evidential deficits addressed before their use becomes critical. Nor will they benefit from the economies of scale and learning (Foxon, 2007) required to meet the market need for cost and risk minimisation.

When viewed on a short term, project-by-project basis it may be rational to reject the use of NMS where expectations are set on the assumption of DMS use. This argument holds until the elaborating impacts of implementation are outweighed by the costs of inaction – the need to reduce construction output, or raised costs resulting from government intervention. When this crossover occurs, the investment necessary to address the information and performance deficits will need to be made, rapidly advancing an NMS's technology readiness level on one project to enable implementation. This investment of time and costs will fall upon one project and client, a significant first mover disadvantage. Spreading the required investment over multiple projects can reduce the risk of sudden dislocation for an individual client or project.

Unfortunately, the decision-making horizons in the UK construction industry are typically short, while the time taken to develop, evidence and diffuse new materials is long: There is a clear *"clash between a long-term, sustainable, business model for multiple stakeholders and a model that is entirely focused on shareholder primacy"* (Daneshkhu and Barber, 2017). As investors and clients turn to assessing longer term threats to organisational value resulting from poor environmental stewardship, motivated by their fiduciary duties, environmental pre-financial risks will receive more attention – the potential economic loss is closer, and investment to avoid the loss becomes more likely.

The majority of UK construction clients do not currently appear to perceive the long-term value implications of an investment in the adoption of low embodied GHG materials (data point AL). In turn, this limits the market signals to potential producers of NMS. However, as the UK's

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<sup>12</sup> This section reprises the discussion presented more expansively in Appendix A.

carbon budgets tighten, the pressure to reduce embodied GHG on construction projects will increase, creating a sudden performance gap relating to embodied GHG. Raising the profile of this impending transition risk of dislocation (data points AW, AY) with repeat construction clients and the investment community is considered to be a critical step in motivating clients to provide project opportunities for low embodied GHG NMS implementation.

#### **10.6 Conclusion: Interventions to Promote NMS on a Project-by-Project Basis**

This assessment of the proposed interventions to promote NMS on a project-by-project basis paints a bleak picture of a project actor's ability to intervene to ensure NMS implementation on a project. The majority of interventions proposed are either unavailable to specifiers, or influence only their own motivations or capability to implement an NMS. While such interventions are supportive of the process of innovation generally, they ignore the critical need for an opportunity to specify NMS. This opportunity arises when interventions address client or context project performance objectives that the dominant solutions cannot satisfy. Such 'top down' interventions can drive NMS specification and implementation.

Client level performance gaps supportive of NMS specification might be created by articulating the short and long-term value propositions presented by investing in NMS specification, in particular, value generated by the avoidance of transition risks. Such performance gaps can create both the opportunity, and through procurement route selection, the motivation for specifiers to propose NMS on projects.

The next chapter explores the implications of these findings.



## 11 Implications for Policy and Practice

*“Who gets the benefits from innovation? Are they reinvested in the innovators? If not, the industry will fail.”*

*Speaker, Data point BC*

### 11.1 Introduction

The framework presented in Chapters 8 and 9 of this thesis has highlighted the key role of the client and context in creating the opportunity to implement NMS on construction projects. Chapter 10 has described how this opportunity might be identified or created on a project. Chapter 10 further details how project interventions proposed in prior literature fail to address this need for an opportunity, focusing instead on specifiers' motivations and capabilities. This chapter now discusses the implications of the research for those interested in promoting NMS specification and implementation on construction projects.

### 11.2 Implications for Policy

Delays in responding to the need to reduce the embodied GHG on projects represent a form of market failure – there is no clear competitive advantage in specifying NMS. Governments have a role in addressing this market failure by intervening to direct the industry away from their high embodied GHG trajectories (after McDowall, 2018) supporting a smooth transition. The framework presented above highlights that if governments do this by setting appropriate context performance objectives relating to embodied GHG use, they can create context performance gaps that all construction projects must address, forming the basis for competition in the sector. Unfortunately, in the UK, there is currently no overarching policy ownership driving this transition (Roelich and Gieseckam, 2018). This should be remedied.

Further, regulations can be enacted that require that embodied GHG be reduced on projects in a similar manner to which reductions of operational GHG are managed. However, if embodied GHG are to be regulated through pricing signals or by performance requirement, it is important that there is a consistency of data and method of calculating material impacts. The government should support the development of the common methodology for calculating the embodied GHG of buildings recently created by the UK's RICS (RICS, 2017) to enhance this certainty.

The government can also stimulate the innovation and supply of NMS through government procurement policies, sending a market signal to providers. Alternatively, suppliers may be supported more through direct or indirect subsidy to facilitate the enhancement of the technology readiness levels of their products, although this may require the government to 'pick winners' which it has been cautioned against (Stern, 2006). In each of these cases, the government is undertaking investment to advance NMS readiness. However, this is likely to be resisted by the current UK government as it may be considered to be crowding out private investment. Price or tax instruments might instead be used to incentivise value creation on projects through the use of NMS. These interventions act as a cost disincentive against the use

of high embodied GHG materials by increasing their price relative to NMS. Carbon trading schemes serve a similar purpose and may, in time, influence purchasing decisions for some energy intensive sectors.

Finally, the government also has a role in encouraging or requiring companies to explore the impending risks of climate change through the use of GHG related non-financial reporting requirements. In particular, the recommendations of the Task Force on Climate-related Financial Disclosures ([www.fsb-tcfd.org](http://www.fsb-tcfd.org)) suggest that company directors report on the risks and opportunities presented by climate change for their organisation, including physical and transition risks. Such reporting increases the saliency of these risks to investors and company directors (data point AY).

### **11.3 Implications for Project Actors**

#### **11.3.1 Clients**

*“If you want a revolution, you have to address the client.”*

*Data point AQ*

Without contextual requirements requiring consideration of embodied GHG, the next level of the project hierarchy with the power of sanction over other project actors is the client. They are uniquely positioned to both require and enable project teams to factor in the use of low embodied GHG materials into their projects. On individual projects, the ordering and timing of specification decisions has been shown to be important in ensuring the capability to implement NMS. Where a project's designs are allowed to develop before the fixing of budgets and timelines, the opportunities to specify NMS on projects are enhanced. However, clients may be unwilling to commit to significant design fees and the recruitment of project teams until the project has organisational authority to proceed, requiring the setting of budgets. Clients should be explicit if they have a wish to introduce NMS, establishing sanctionable performance requirements or expectations, or incentivising the delivery of project aspirations in line with PBO value drivers. They should also provide the physical resources to accommodate the elaborating impacts of the decision (slack) to implement an NMS. This removes the pressures on the NMS and project team to compete in terms of time and cost, creating an active niche.

#### *One-off Clients*

This research has highlighted that the implementation of low embodied GHG NMS on one-off construction projects requires that the client actively values the use of such solutions on their project, either in response to an organisational mission, or by their providing other financial or near financial benefits. Such one-off projects are unlikely to be immediately impacted by the tightening of carbon budgets. However, if a client intends to retain ownership of the building over its lifetime, or indeed acquire an existing building, the building's refurbishment and maintenance cycle will need to be considered. If a building is initially constructed on the assumption of the continued availability of high embodied GHG materials, radical changes may be required to the building if these materials are no longer viable due to GHG pricing, taxation,

the withdrawal of actual or social license to use these materials. Faced with such price increases, they will need to consider supporting the additional costs of evidencing performance of replacement solutions. When procuring, or acquiring a building, one-off clients should consider these additional GHG related costs in their life cycle planning.

### *Repeat Clients*

As the UK's carbon budgets become tighter, regulation, or GHG pricing may cause the current dominant solutions to become more expensive, or unfeasible on projects. Further, their use may be considered inappropriate in the future, impacting their producers' license to operate. Construction clients' ability to maintain their construction output volume and margins using the current DMS may be threatened, risking their ability to deliver on market expectations of profitability, or to meet their funding obligations. They will, at some time, be required to adopt NMS and incur the associated costs to address remaining evidential deficits. For repeat clients, encouraging their project teams to explore NMS on early projects can enhance their long-term organisational resilience to these transition risks (data points AH, AV). However, as the industry's fragmented delivery structures mean that suppliers are free to supply other projects, early uptake by a first-mover can reduce future cost and time burdens for all.

For repeat construction clients, the decision to invest in NMS implementation is a question of remaining competitive by the avoidance of additional time and costs on projects. The need to use NMS is likely to be resisted for as long as possible by many clients, in the hope that others will take the first step and make the investments necessary to enhance technology readiness, and address the various elaborating impacts of NMS. Unless a conscious decision is taken by a client to advance NMS use, these impacts could ultimately fall on any one project – who blinks first?

It would seem reasonable, therefore, that the costs of evidencing NMS should be socialised among the actors in the industry who stand to benefit, those many companies impacted by a sudden need for evidence and skills, ultimately construction clients. In other words, the drive to reduce embodied GHG could become a pre-competitive concern (data point AB), with the risks and costs addressed collectively, rather than by the first movers, and in good time to meet the needs of the UK's carbon budgets. Indeed, given the actor unwillingness to share privately acquired knowledge (data point AQ), such a collaborative, pre-competitive approach may be more successful than relying on competition.

Addressing the issue in this way could involve the professional institutions, academia, clients, material producers (or their industry bodies) and PBOs working collectively to identify the risks and needs of transition. Awareness can be enhanced influencing actor motivations and the opportunity to implement NMS. The elaborating impacts of the innovation process would also be reduced, creating a significantly enhanced cost benefit on the individual project. In particular, supporting the institutionalisation of codes and best practice can reduce the elaborating costs of

acceptance and validation for all. The costs of achieving this could be spread, not only over time, but across organisations. Financial input could be sought from Government.

### **11.3.2 Project Managers, Quantity Surveyors**

*“[Their] duties are a real barrier to innovation in my view.[...] rarely do you hear the PM or cost manager talking about the quality of delivery, things that were done differently, legacies that were left.”*

*Data point 9, project manager*

Project managers and quantity surveyors are engaged on projects with a duty to ensure the effective delivery of the client's expectations in particular relating to time and cost. The delivery of more than the minimum to meet client expectations of quality is considered wasteful. However, at the initiation of the project, clients rarely have a clear picture of what they want. If a client does not articulate a need for low embodied GHG materials at that point in time, the managed baselines for time and cost performances will typically be established using assumptions on the use of DMS to meet the project's performance objectives. Work proceeds to ensure that these targets are met, typically by the operation of underlying assumptions.

The morphogenetic perspective of the project adopted here highlights how the duties of these two PBOs restrict the implementation of NMS and other innovations on projects by explicitly restricting key slack resources on projects, with tightly described contracts restricting DMU decision horizons. These PBOs, typically engaged early in projects, have the opportunity to influence a client's project performance objectives and committed endowments to both enable and accommodate NMS implementation.

In time, the need for NMS will arise on projects. When this happens project time and cost budgets established on the assumption of DMS use will prove inadequate due to the elaborating impacts of NMS specification and implementation. In turn, this may cause significant overruns on time and cost budgets, leading to a loss of professional reputation or sanction on individual projects. It is therefore in the self-interests (avoidance of pre-financial risk) of project managers and quantity surveyors to develop their capability to understand how climate related transition and resilience risks will influence the construction of buildings, including the time and costs of delivery. This will enable them to prepare more accurate project baselines that account for the forthcoming transition, and to anticipate the associated regulatory change.

### **11.3.3 Industry Bodies**

If the government remains unwilling to regulate to create a performance gap relating to low embodied GHG NMS, and an associated competitive advantage in creating such NMS, it falls to the market to respond. The long-term changes required in a fragmented industry are such that a coordinated, pre-competitive approach should be considered to encourage the development of low embodied GHG NMS (Section 11.3.1). One of the roles of industry and professional bodies is that of coordinating and disseminating new knowledge. These bodies should foster

strong links between industry, academia and policy, increasing the flow of knowledge between them. This engagement could also lead to the development of a cross-industry innovation platform and knowledge base to promote NMS on projects. Professional bodies should review their training requirements to ensure that their members are aware of the longer term risks of non-adoption, and to motivate them to develop the necessary capabilities to reduce the impacts of search, selection, validation and implementation when the opportunity arises to specify NMS. Industry organisations should encourage their members to develop their evidence base and enhance their marketing opportunities. Groups representing clients should also be helping to create the demand for NMS, reinforcing the need for change in the long term by encouraging their membership to explore the transition risks on their businesses.

Professional and industry bodies should also develop a coordinated campaign to influence policymakers to deliver regulation that creates a contextual performance requirement relating to embodied GHG. This would deliver the sought after 'level playing field' for project actors, and certainty for those investing to develop NMS. Some of this work is already underway, with RICS consulting widely in the development of their Professional Statement on the calculation and reporting of 'whole life carbon' on construction projects. This work should be accelerated to create the institutions around embodied GHG that exist for operational GHG impacts.

#### **11.3.4 Specifiers**

Section 10.4 has highlighted the opportunity to introduce NMS to a project may be created by identifying or influencing sanctionable context or client project performance objectives that preclude the use of DMS on projects. Alternatively, where resource budgets have been established, implementation may occur where the NMS performs at least as well as the DMS on the key project performance objectives of price and time and offers some additional benefit that is valued by the client. While this client or context led demand provides the opportunity to specify NMS, specifying and coordinating PBOs must also have the motivation and capability to implement NMS on projects.

To date, the motivation to specify and implement low embodied GHG NMS on projects has largely been mission-led, driven by personal value drivers. However, the risks of dislocation described above apply equally to specifiers as it does to clients. Engaging with NMS early will ease their transition, spreading their learning costs over a longer period, enabling them to develop capabilities that may also deliver a competitive advantage over those specifiers that are unprepared for the transition. Enhancing the cultural endowments of knowledge, knowledge sharing and absorptive capacity will reduce the elaborating impacts of NMS specification when the time arises, protecting performance at the organisational level. PBOs should support their staff to develop an understanding and awareness of the NMS on the market.

Further, PBOs and DMUs wishing to innovate on specific projects should identify and locate their own performance objectives and consider how these might align with performance requirements and expectations of the client. Where there is an overlap in objectives, NMS or

other innovations can be proposed to create value for the DMU and client. Further, if competition permits, slack resources should be built into each bid to provide for the potential elaborating impacts of any NMS specification. Training and resources should be made available in organisations to enhance capability in search, selection, validation and implementation as appropriate.

Where possible, proposals for the use of NMS on projects should be made before the client's project performance objectives are established for time and cost, and other PBOs' resource commitments are fixed. However, it is not always possible to engage directly with the client early in the project to encourage them to adopt a PBO's performance objectives. Networking with and presentations to those who are engaged early, highlighting the transition risks might influence their interactions with clients in course and build trust.

### **11.3.5 Material Suppliers**

#### *Suppliers of NMS*

Innovation in construction is typically undertaken in pursuit of competitive advantage. However, this competitive advantage can be quickly eroded in the market place, with the financial benefits of innovation being rapidly appropriated by the client, or contractor (Appendix A, data point O). If the investing company is unable to make a return on their investment due to this appropriation, their motivation to invest further in research and development is diminished. As has already been the case with bio-based NMS, suppliers may exit the market (Interviews 1, II), and other potential suppliers may be deterred from market entry, leaving only suppliers of high embodied GHG solutions.

However, the demand for NMS to the construction market is expected to grow as the existing dominant solutions become inappropriate for use on projects due to their high embodied GHG. While this demand may provoke NMS specification, this research has highlighted that the elaborating impacts of NMS specification can still deter implementation of particular technologies. To enhance the likelihood of specification and implementation, time, cost or other relative advantages of the NMS over the existing solutions should be highlighted and evidenced. Any relative disadvantages should be identified and mitigated such that negative impacts on typical project performance expectations are minimised. Further, the anticipation of elaborating impacts of specification on projects should be minimised by:

- Absorbing or sharing the transaction costs deficits if possible.
- Ensuring that specifiers are aware of the product, reducing their costs and time of search.
- Providing evidence and certification of typical performance attributes (e.g. fire, acoustics, strength) relating to requirements and expectations, in a suitable format.
- Minimising the changes necessary elsewhere on the project from the implementation of the NMS, both within and across 'swim lanes' (Section 9.4.5).

- Maximise the NMS's perceived technology readiness level. Use niche projects to advance knowledge, and promote NMS specification and implementation in the trade press.

Construction innovation diffusion occurs very slowly, often over decades, and different organisations have differing speeds of uptake. Products hoping to address the need for low embodied GHG should be introduced to the market as soon as possible to allow this diffusion to happen. While this is relatively easy to recommend, achieving a broad diffusion requires a significant investment of time and resources that may not be available to the organisation promoting the NMS. Suppliers of NMS should consider accessing the sustainable finance market to fund the development of the product. The market includes lenders and 'patient investors' who focus on longer term lending and 'socially responsible investments' (KK, 2018).

#### *Suppliers of DMS*

If countries around the world abide by the requirements of the Paris Agreement, the demand for many GHG intensive materials is likely to fall significantly, their use being incompatible with a 'net-zero' world. Suppliers of these GHG intensive solutions should explore the impact of transition on their business models. In particular, they may wish to explore the risk of financial loss resulting from a fall in demand, and the risk of stranded assets (Lehne and Preston, 2018). Addressing this risk now will allow suppliers to plan a strategic response to the transition ahead. However, the long term (>10 years) and uncertain nature of the timing of loss may cause suppliers of DMS to postpone this exploration, at their own risk.

### **11.4 Implications for Academia**

This section discusses the role of academia in NMS implementation on projects. The opportunities for further study are discussed below.

Section 6.2.3 described how academia can also become locked-in to the delivery of knowledge relating to the dominant solutions in construction. This institutionalisation ensures that graduates are equipped with the knowledge they need to assist in the delivery of dominant solutions, becoming productive for their employers soon after graduation. However, students currently proceeding through the university system will be responsible for delivering the transition to a 'low-carbon' economy during their careers. Providing them with knowledge on the dominant solutions alone will not equip them to do so. Further, the analysis of the specification decision in Chapter 9 highlights the roles of both technology readiness and decision-makers' knowledge (cultural endowments, capability) in reducing the elaborating impacts of the NMS specification decision. Academia has a role to play in influencing both. As degree courses become more closely aligned with industry requirements, it is important to ensure that these requirements are sufficiently forward looking, engaging with the notion of transition. However, to assist with transition, students must also be taught about the process of search, selection and validation of novel solutions, and the need to develop their absorptive

capacity. Collectively, these skills will help to reduce the elaborating impacts of NMS specification when the opportunity to specify one presents itself.

There is also a role for academia in meeting the need for a rapid expansion in the evidence base supporting NMS implementation. By assisting NMS suppliers in the testing and certification of their products, universities can help advance the technology readiness levels of an NMS, easing their route to market by reducing the perceptions of the elaborating impacts of implementation. Working with material and product manufacturers, or industry bodies, such as the UK's Construction Product Association, to develop this evidence base presents a financial opportunity for academic institutions.

### **11.5 Conclusion**

This thesis has provided a systematic approach to the assessment of interventions to promote NMS on construction projects. A review of the framework has indicated weaknesses in the UK's current response to the challenges of transition to a 'low carbon' economy. This chapter has highlighted the implications and provided recommendations for key actors with an interest in the construction industry. By adopting these recommendations and addressing the implications, the transition risks on organisations and the wider economy might be reduced.



## 12 Conclusions

### 12.1 Summary of the Research

The UK Government has made commitments under the Paris Agreement and the UK's Climate Change Act to significantly reduce the levels of GHG emitted in the UK. If the UK construction sector is to play its part in meeting these commitments, new ways of creating the built environment will need to be adopted. This thesis has explored how project actors might intervene to influence the specification of novel material solutions (NMS) on projects.

With the researcher based in an industry setting, the study adopted an auto-ethnographic, constructivist grounded approach to theory development, gathering data from multiple sources including: surveys, interviews, focus groups, and participatory and non-participatory observations. The study explores the UK construction market, and more narrowly, in the context of bespoke construction projects. The UK was chosen due to the location of the researcher. Bespoke projects were selected because they reflect most clearly the emergent characteristics of the construction projects and the fragmented nature of the industry, with volume housing being considered as more akin to manufacturing, and infrastructure being large but relatively uncommon.

Phase one of the study, reported in Jones (2014), Jones et al. (2016, Appendix F), highlighted the role of actor motivations in the (non-)implementation of cross-laminated timber (CLT) onto projects, providing a focus for the second phase of the research. However, the data gathered during the second phase suggested that actor motivations – evidenced in their performance objectives for the project – and the contingent, emergent project circumstances could either support or undermine NMS specification and implementation on projects. Accordingly, there was significant uncertainty as to which of the interventions proposed in the literature could create the necessary specification behaviour change on projects (Objective 1). A systematic approach was needed. Phase two of the study used a morphogenetic perspective of structure and agency to explore the specification decision, the adopted unit of analysis. A review of existing models of the construction project failed to identify a suitable contingent and emergent model in which to locate specification decisions. In response, a new context sensitive, dynamic middle-range model of the construction project was developed (Objective 2). This model provided a framework within which the hierarchical, contingent and time-dependent structural influences on the specification decision could be analysed (Objective 3). The framework highlighted how a proposed NMS's technology readiness level (TRL) determines the need for PBO and project resources to address the elaborating impacts of the specification proposal. Further, the framework highlights how the timing of the specification decision and the assumptions underlying resource commitments influence the availability of those resources at the point of specification.

In recognition of the need for specification behaviour change, the research integrated perspectives from the behavioural sciences, exploring the influences of proposed interventions

on the capability, opportunity and motivations of the project actors to specify NMS. This interaction was assessed in light of the framework set out in Chapters 8 and 9 (Objective 4). This highlighted the distinct intervention actions of (a) reducing the elaborating impacts of NMS specification and implementation, and (b) establishing motivations to specify NMS at client and PBO levels of the project hierarchy. By aligning the impacts of the intervention and the needs of the project context to support NMS specification and implementation, case-appropriate interventions can be identified (Chapter 10). A methodology for analysing the needs of each project contexts is important future work.

A challenge in middle-range theorising about construction projects is that high levels models of the project presented to date are too abstract, limiting operationalisation. On the other hand, explorations of projects at the levels of the specific – activity and decisions – can be highly complex, but lack external validity. By adopting the specification decision as the unit of analysis and describing a way to locate and analyse the decision, this thesis bridges that gap, providing both a middle-range range model of the construction project, and a means by which it can be operationalised.

## **12.2 Contributions to Knowledge**

This study contributes to the construction management literature and practice by the development of a novel morphogenetic, descriptive framework in which to locate specification decisions, and assess their conditioning structure and elaborating impacts. With this knowledge, case-appropriate interventions can be selected to promote NMS implementation on a case by case basis. A review of the framework presented in Chapters 8 and 9 highlights practical recommendations to accelerate the transition to a low embodied GHG built environment.

As well as providing a framework within which researchers and practitioners can assess the specification decision and proposed interventions to encourage NMS specification on a particular project, it is modestly proposed that the theory may also provide a suitable framework in which to locate future construction management research.

## **12.3 Limitations**

Developing theory directly from limited observed data can reduce both the reliability and external validity of studies. This study has been undertaken through a process of abduction, with the researcher going beyond the data, interpolating and triangulating between data and theory to reach a plausible account of the phenomenon of NMS implementation in projects. These explorations and the subsequent ‘flashes of insight’ are implicitly influenced by the researcher’s experiences, their understanding of the problem, and their engagements with industry. While objectivist researchers may consider this bias to limit this project, attempts have been made to reduce this bias by the use of multiple observations, theoretical triangulation and continuous sampling to the point of data saturation. Further, the outcomes presented here are

also recognised as offering only provisional descriptions of the problem of NMS implementation, subject to additional exploration and testing as described below.

The framework developed in this thesis has been developed to be adaptable to any project context, including housing and infrastructure projects, and other project or PBO decisions. As such, is the framework, and findings of this research are considered to be generalisable to other project conditions, and, with care, other countries.

#### **12.4 Proposals for Further Research**

The morphogenetic perspective of the construction project adopted in this thesis is novel and has provided actionable insights for those seeking to implement NMS on construction projects. However, this analysis should be taken further through the application of the morphogenetic perspective to the analysis of longitudinal case studies, exploring the influence of the sequence of decision-making on projects. In particular, international comparative studies would provide helpful insight into the role of project contexts on NMS specification and implementation. This will assist in understanding how early decisions influence project actors' capability, motivation and opportunity to implement NMS on projects. Such studies should extend the scope of application of this study beyond the bespoke building project to include the housing market and infrastructure. The findings of this study further suggest that research efforts should be directed on four fronts to promote the uptake of low embodied GHG NMS onto construction projects:

- The development of a methodology for analysing specific project contexts.
- Exploration of the influences of client sustainability related performance requirements, expectations and aspirations on project outcomes.
- Enhancing the technology readiness of NMS to reduce information deficits.
- Developing a richer understanding of the key transaction costs associated with NMS implementation, building on Figure 37.

Finally, decision-making under uncertainty is one of the defining characteristics of the construction project development process. Recognising the influence of uncertainty on NMS specification, several specific research questions have been identified for future exploration.

- What is the correlation between knowledge of an NMS and the gaps between actual and perceived TRL in construction materials?
- How does the format of evidence influence search?
- How does the perception of an NMS's technology readiness level (TRL) influence actor uncertainty?
- How does trust between specifying and coordinating PBOs influence the perceptions of uncertainty in specification decisions?
- How does actor uncertainty influence the anticipation of transaction costs across the implementation process?

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## Glossary

Abductive inference / abduction	The re-interpretation and re-contextualisation of observed phenomena within a (new) conceptual framework or set of ideas (Danermark, Ekstrom and Jakobsen, 2002).
Carbon dioxide	Carbon dioxide (CO <sub>2</sub> ) is a key greenhouse gas that causes warming of global systems, leading to climate change.
Conditioning structure	In this thesis, a decision's conditioning structure represents the constraints on a decision-maker's exercise of agency. It is made up of both explicit and implicit constraints resulting from the socio-cultural, technological, organisational and economic context in which the decision takes place.
Construction industry	The construction industry is defined widely in this thesis. The definition incorporates but is not limited to contractors; their supply chains; designers and other consultants; the construction client and their advisors; insurers; and financiers etc..
Critical realism	A meta-theoretical philosophical framework " <i>concerned with providing a philosophically informed account of science and social science which can in turn inform [...] empirical investigations</i> " (Archer et al., 2016) Critical realism accepts the realist position that there is an objective reality, but holds that attempts to describe that reality are fallible.
Decision-making Unit (DMU)	The body that explores and reaches a conclusion on a decision. This could be an individual or a group of individuals working together.
Decision set	The range of decisions required to be made to reach a particular goal.
Dominant Material Solutions (DMS)	These are the materials that would be typically used as construction materials where there is no consideration of embodied greenhouse gases. The material will vary by context, but typical examples are the use of concrete and steel for the production of a building's structural frame.
Drivers of value	Value is " <i>...the capacity of a good, service, or activity to satisfy a need or provide a benefit to a [decision-maker]</i> " (Baier and Rescher, 1969). It is a subjective reflection of the importance or worth of some object, impact or action to a decision-maker. Drivers of value describe those objects, impacts or actions to which an individual ascribes value.
Elaborating impacts	The (potential) impacts brought about by an individual's (proposed) exercise of agency.
Embodied greenhouse gases (GHG)	In this thesis, these represent the non-operational greenhouse gases associated with the cradle-to-grave life cycle of a construction material, i.e., emitted during the extraction, production, transport, construction, maintenance and end-of-life of the construction material.
Emergence	" <i>The process of coming forth. Also [...] the result of an evolutionary process</i> " (OED Online, 2018). In the context of the construction project, emergence is the characteristic that describes the development process in which decisions are made over time, reducing uncertainty.

Greenhouse gases (GHG)	The gases that cause planetary system warming due to their accumulation in the atmosphere. The impacts of the different gases are measured in terms of their equivalence to the impacts of carbon dioxide (CO <sub>2</sub> e). The six main greenhouse gases are carbon dioxide (CO <sub>2</sub> ), methane (CH <sub>4</sub> ), nitrous oxide (N <sub>2</sub> O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF <sub>6</sub> ).
Heuristics	Mental short-cuts employed by individuals when making decisions to reduce complex probability judgments to simpler ones (Tversky and Kahneman, 1973).
Information deficit	The information shortfall relating to a construction product that means an actor is unwilling to specify the product.
Innovation diffusion	The spread of an innovation across an industry or organisation.
Institutions	Institutions are “ <i>humanly devised constraints that structure political, economic and social interaction</i> ”, including “ <i>both formal and informal constraints</i> ” (North, 1991).
Lock-in	The end point of a path-dependent process of technology adoption in which positive feedbacks mean that the more a technology is adopted, the more likely it is to be further adopted. The lock-in of incumbent technologies can prevent the uptake of potentially superior alternatives (after Foxon, 2007)
Material Adoption Model	A model of the material adoption process developed at the end of phase one of the research. It is included as proto-theory 6 in Appendix C.
Morphogenesis / Morphostasis of Agency	A perspective on the question of structure and agency that “ <i>maintain[s] an analytical distinction between structure and agency</i> ” (Porpora, 2013). Where the exercise of agency (cultural interaction) transforms the structures in which decisions are made, morphogenesis occurs. Morphostasis occurs when the decisions reproduce the pre-existing structures (Archer, 1998).
Multi-Level Perspective (MLP)	The MLP is “ <i>a framework for understanding sustainability transitions that provides an overall view of the multi-dimensional complexity of changes in socio-technical systems</i> ” (Geels, 2010)
Novel Material Solution(s) (NMS)	Novel material solutions are those that are new to an actor, organisation or other decision-making unit (DMU) (after Sepasgozar and Bernold, 2012). In the context of this thesis, the description applies to materials, technologies and processes with lower environmental impacts than the current Dominant Material Solution. It may not necessarily be new to the market.
NMS implementation	The act of incorporating an NMS into a construction project. Once this process is complete, an NMS is said to have been adopted onto a project.
NMS specification	The proposal for use of an NMS on a construction project.



Operational GHG	The greenhouse gases emitted in the operation of a building.
Residual uncertainty	Residual uncertainty exists where there is an information deficit ( $qv$ ) relating to an actor / NMS combination.
Risk	Typically, risks are described as unknown outcomes for which known probability functions can be drawn. However, in construction and in this thesis, Hillson and Murray-Webster's (2007) more general definition is adopted, with risk being described as an uncertainty that influences the achievement of objectives.
Structure and Agency	The structure and agency debate lies at the heart of social enquiry. It centres on the extent to which an individual's exercise of agency is conditioned by structures external to them.
Technology Readiness Level	A measure of the maturity of an emergent technology. See Appendix E for further information.
Uncertainty	Unknown outcomes for which a distribution of possible outcomes cannot be described.

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## **Appendices**

Appendix A – Cost-benefit Exploration of the NMS Specification Decision

Appendix B – Participatory and Non-participatory Observations

Appendix C – Memo-writing: Diagrammatic Memo Evolution

Appendix D – Schematic: Interpretation of Human Sense-making

Appendix F – A Copy of Jones et al., (2016)

Appendix G – A Copy of Jones (2017)

Appendix H – A Copy of Jones et al., (2017)

Appendix I – A Copy of Jones, Martin and Winslow (2017)

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## **Appendix A – Cost-benefit Exploration of the NMS Specification Decision**

This Appendix summarises and re-presents the literature in this thesis to describe the NMS specification decision on construction projects in terms of an economic, cost benefit analysis. While important, this discussion has been included as an Appendix so as not to interrupt the narrative flow of the main thesis, which presents the journey on which the researcher went.

### **Fundamentals of Adoption: Value, Cost and Risk.**

New buildings are developed with the aim of creating additional value, be that economic, functional, social or environmental (Spencer and Winch, 2002; Saxon, 2005; Mills, Austin and Thomson, 2006). Fundamentally, the adoption of new techniques or materials on a construction project are undertaken to enhance a building's value proposition. The analysis undertaken to decide whether an NMS should be adopted on a project is a consideration of the relative cost, benefits and risks of that adoption (e.g. Maine and Ashby, 2000). To overcome material lock-in, the overall value (broadly defined) that a new material brings to the project must be higher than the total cost. If barriers are presented, implementation requires that value be enhanced, or the expected costs of implementation reduced.

### ***Costs of Adoption***

When considering the cost of a transaction, concern frequently turns to the price of an item. New products, which have not had the benefits of path development, learning by doing and the associated economies of scale, can often be more expensive than the incumbent dominant solutions (Foxon, 2007). Certainly, there is a market perception that this is the case (Williams and Dair, 2007; Gieseckam, Barrett and Taylor, 2015). However, the implementation of an entirely new, unfamiliar, approach requires additional non-product related costs to be incurred. These reflect the costs of learning about the new material and amending internal processes and systems to successfully work with the new material. Perceived additional costs also reflect the uncertainty inherent in new products that require increased monitoring due to higher uncertainty and risk of failure. Qian et al. (2015) explore these costs associated with sustainable building products, finding that the greatest area of concern was the *“possibility of extra legal liability in relation to the product due to uncertainties about the market, consumers, and available technical information.”*

Such costs are described as transaction costs by Williamson and Tadelis (2012), and reflect the information asymmetry arising from a fragmented market place. The specific nature of these costs in relation to NMS implementation has recently been explored in relation to sustainable building (Qian, Chan and Choy, 2013; Qian et al., 2014; Qian, Chan and Khalid, 2015; Qian, Fan and Chan, 2016). In particular, Qian et al. (2015) found the extra legal liability risk from 'green building' products to be the major concern for potential developers in Hong Kong. Some of these transaction costs will necessarily be borne by the implementing organisation through learning, training and systems changes. Other costs though, addressing information

requirements, might be borne by the material manufacturer, a testing authority or an early adopting client. These information requirements are discussed further below.

Further, in an integrated systems environment such as a construction project, change is costly in itself. Alterations in a single element may have ramifications for many others if changes are required to accommodate that element (Abernathy and Utterback, 1978; Henderson and Clark, 1990; Slaughter, 1998; Sheffer and Levitt, 2010), leading to expectations of higher implementation costs across the project.

### ***Information Hygiene & Residual Uncertainty***

Before adopting a material, a specifier will require that certain attributes of that material be evidenced. This evidence can be provided through a combination of material data sheets, EPDs, certificates and warranties. If the supplying company is able to evidence the attributes required by the specifying company, the material can be included in the range of options for further consideration: it has demonstrated sufficient information hygiene for a given specifier at a given point in the design process. This may not be the case for specifiers with lower tolerances for uncertainty (Figure 46) who will be faced with an information deficit and accordingly will be left with a residual uncertainty over the performance of the material.

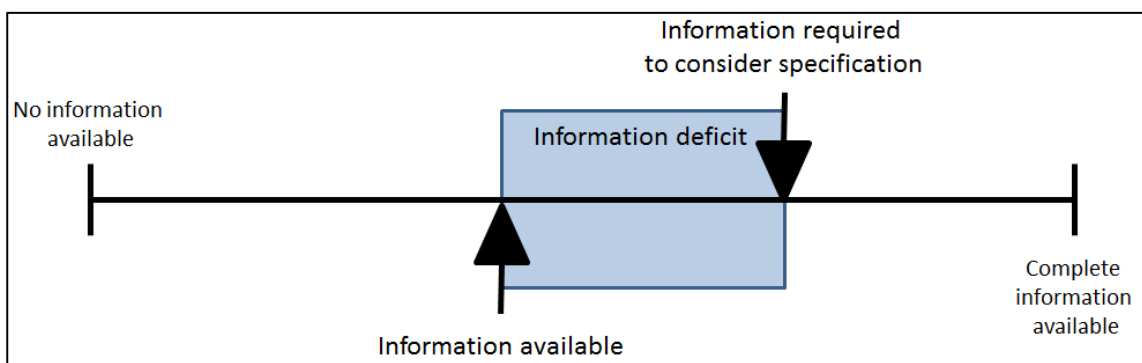


Figure 46 – Information requirements and availability

However, a material that is new to the market may not yet have any of the required evidence or certifications in place – it demonstrates insufficient information hygiene for all. In the face of an information deficit, an organisation considering adopting the material must address their residual uncertainty, that is, the data gap between the required and available data.

This will necessitate testing and certification of the material in question, requiring an investment of time and resources. This investment might be made by the material provider, the supplier, the specifier, or some external funder. The willingness of a specifier or their client to fund this product examination to address the residual uncertainty in pursuit of information hygiene will vary from organisation to organisation, and be a function of the project, context and the value perceived by the client and project team in the material.

### Material Adoption Costs Facing a Specifying Organisation

It is assumed that there is an absolute minimum amount of technical and performance data required before a product can be used in a building project. Such minimal data might be needed, for example, to allay concerns of project insurers or financiers. Without prior investment in the creation of this data, there will be an amount of cost that must be incurred to achieve this minimum data requirement. For simplicity, this cost is therefore represented as an evidential cost line that remains constant over time. In reality, this cost may increase over time as the evidential burden increases, with additional items being included in the requirements for information hygiene.

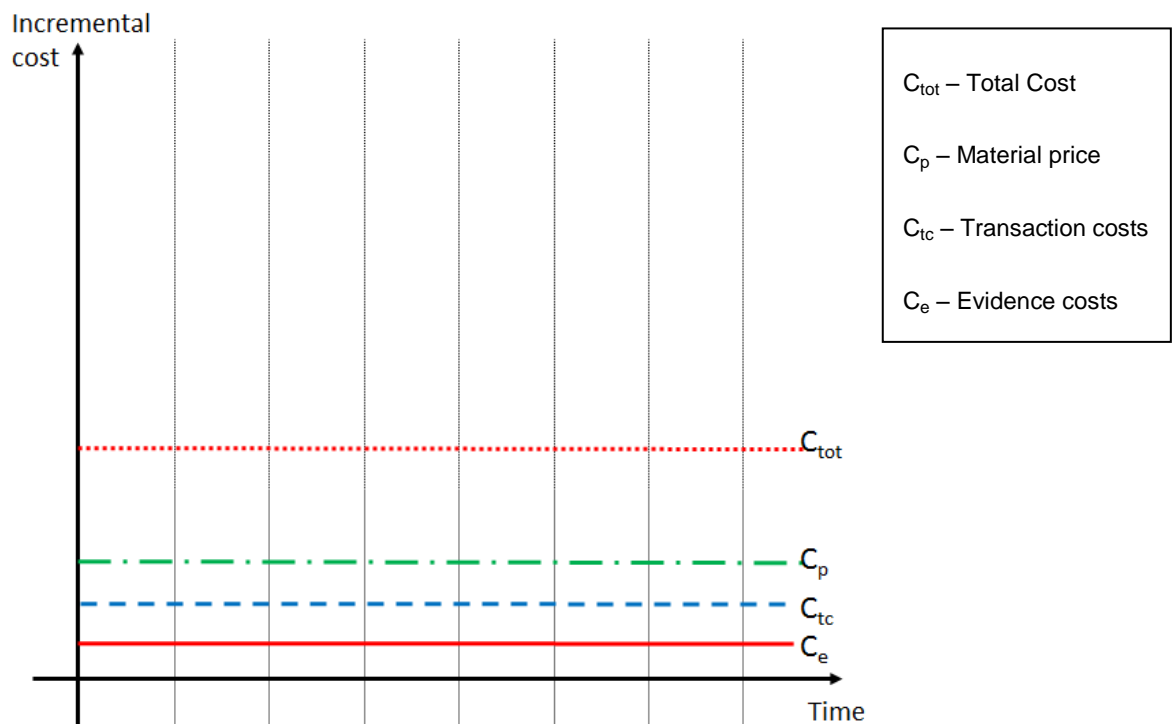


Figure 47 – Material adoption costs for a new material.

Exploring a hypothetical material specification decision, Figure 47 shows such an evidential cost line ( $C_e$ ) parallel to the x axis. Also shown is the additional transaction costs expected to be incurred by an organisation considering adopting the material ( $C_{tc}$ ) from a position of no knowledge in the specifying and implementing organisations, and the installed material price above that of the dominant material solution ( $C_p$ ). The point at which the horizontal axis intersects with the vertical axis represents the cost of the DMS for a given building function. The height of the total cost line  $C_{tot}$  above the x axis – that is, the sum of  $C_e$ ,  $C_p$  and  $C_{tc}$  – reflects the additional actual and perceived costs of adopting a new hypothetical material (NMS) for a specifying organisation at time  $t$  over the currently dominant solution. This assumes that there have been no previous adoptions of the NMS, nor information created related to the NMS. No learning or training in the adopting organisation relating to the NMS is also assumed.

Without mitigating value factors, a profit seeking organisation would tend to resist the implementation of this new material. The function of the NMS could be delivered at a lower cost using the DMS, avoiding evidence and other transaction costs, and the additional material costs that arise from lack of economies of scale and optimisation. As expectations are typically set on projects using a dominant solution, the use of an NMS on a project would lead to a loss (compared to expectations) to the organisation and its stakeholders.

At a point in time,  $t_0$ , (Figure 48) an (external) early adopting organisation decides that they are willing to invest in implementing the NMS in pursuit of additional value on behalf of their project stakeholders. The investing organisation is required to undertake learning and testing in relation to the material. To the extent that the information generated is made available to the market, the evidential costs to other industry actors – including the hypothetical specifying company – will fall. Where information generated is retained privately, a competitive advantage is created for the organisation producing the information due to their reduced evidential and transaction costs for the next implementation. However, information generation on an NMS – typically within a supply chain – are often made available to the wider market to reduce the expected or perceived cost of implementation, encouraging future adoptions.

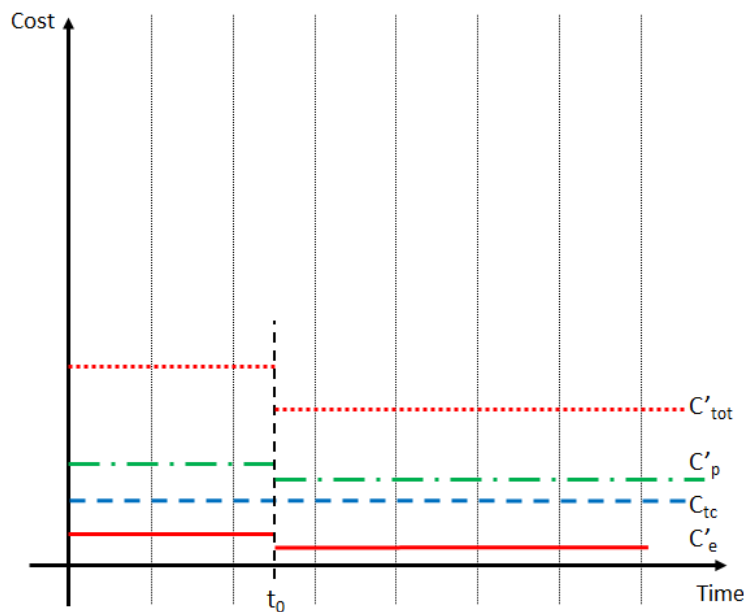


Figure 48 – Material adoption costs of subsequent adoptions

Figure 48 shows the effect of this initial investment, with the evidential cost line ( $C'_e$ ) falling. Further, the product costs ( $C'_p$ ) will generally fall due to of the manufacturer's (or sub-contractor's) learning by doing (Arrow, 1962). The transaction cost line for the external adopting organisation falls as well (not shown) due to of the learning costs they have already incurred, making future adoptions less costly. However, the transaction cost line shown for the non-adopting organisations remains constant ( $C_{tc}$ ), reflecting their lack of learning about the product.



It will be clear that after this initial adoption by an early adopter, both the actual and expected costs of a material to others will fall, benefitting from the evidential investment in the material. This is particularly true when the learnings from this ground breaking project are promoted in trade journals. The first mover is, therefore, financially disadvantaged by the investment in evidence production, while the benefits of their investment are available to others. It is assumed here that the value benefits derived from this investment are non-financial. This is known as the free-rider problem in economics (Pasour, 1981), where actors are able to benefit from the investments of others for little or no investment on their own part; a potential disincentive to adopt new approaches. Subsequent adoptions of the material will further reduce the uncertainty around performance of the material and increase market trust in the product, notwithstanding its relative novelty. This will further cause the expected cost lines ( $C'_e$ ,  $C'_p$ ,  $C'_{tot}$ ) to fall over time.

A characteristic curve for a given product results from this process – the experience curve (EC in Figure 49). The precise shape of the curve will vary depending on the rate of learning relating to the production of a product, but the falling unit cost curve is considered typical for new products (Boston Consulting Group, 1970). The particular material cost line facing an individual organisation looking to adopt a new material will be dependent on where the technology sits on its experience curve, as well as the extent to which it demonstrates information hygiene. While Figure 49 shows the x axis as volume, for simplification, it is assumed that time can be used as a surrogate for volume.

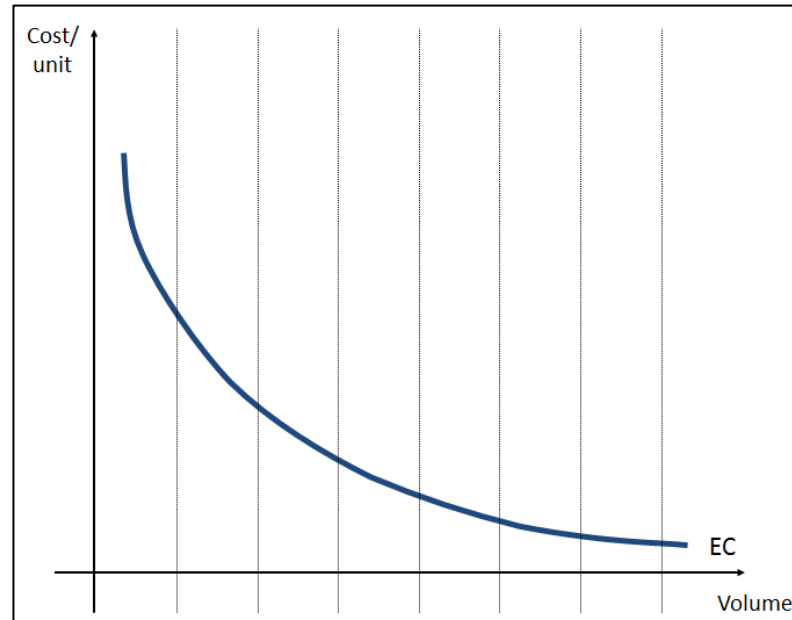


Figure 49 – The experience curve

Figure 50 adopts the experience line shown in Figure 49 as representative of the falling costs of an NMS facing a specifying organisation. Here the line EC represents how the cost of a material falls with adoptions over time across the industry. This fall represents the development

of economies of scale for the organisation the NMS as well as the increased availability of information about the NMS.

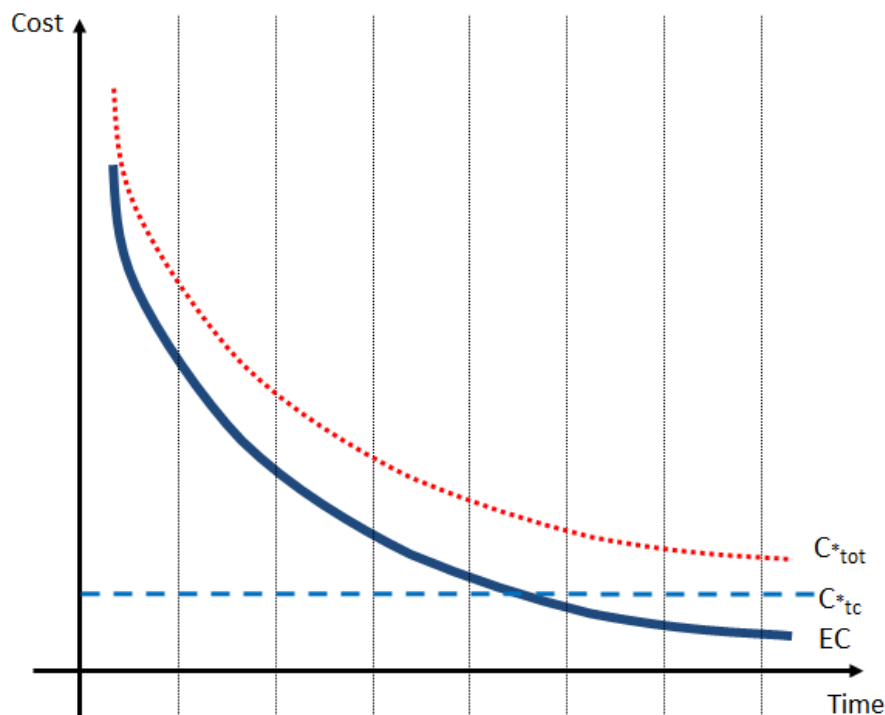


Figure 50 – Impact of transaction costs on total perceived cost

For those organisations who have not previously adopted the material, internal transaction costs ( $C^*_{tc}$ ) must still be incurred, shifting the total cost line to  $C^*_{tot}$ . The transaction cost line is shown as static over time because it reflects the transaction costs – such as learning and training – that must be incurred by a specifying organisation if it is to implement an NMS. Figure 50 assumes that no such investment has been made by the organisation under review.

While the transaction costs are still shown as strictly fixed in this example, in reality, over time, they would fall as knowledge diffuses across the industry. Further, the position of the line EC (and hence  $C^*_{tot}$ ) in relation to the x axis is dependent on the relative price points of the material solutions. There may come a time when the reduction in expected (and actual) total costs fall sufficiently for the costs of the new materials to fall below the costs of the current dominant solution i.e. below the x axis (Figure 51). At that point the new material is likely to become ‘mainstream’ more rapidly for a given application – that is, the new dominant solution to the current institutional framework. It will be noted that for those companies that fail to invest in training and learning, the point at which the cost of the NMS becomes lower than that of the DMS is significantly delayed. This can lead to a competitive disadvantage in a highly competitive market.

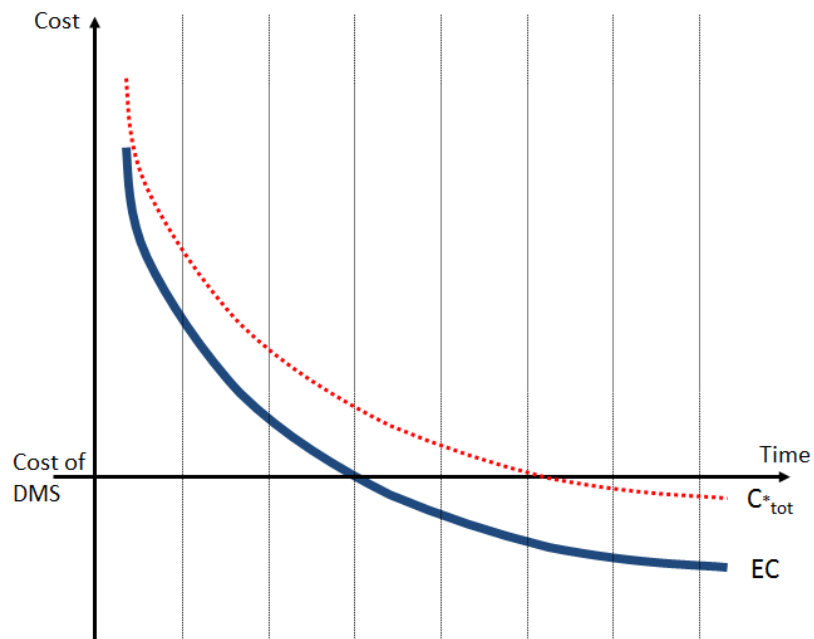


Figure 51 – With experience, new solutions can become the dominant one

Collectively, these lines describe the cost of adopting a new approach over time facing a specifying company: that is, ‘the cost of doing something different’.

### What is Value in Construction?

Value has been described in many ways, from the objective to the subjective. and Mills (Mills, 2013) provides a thorough discussion on the nature and historical development of the concept. This thesis adopts the position that value is a subjective, varying over time:

*“Value is the capacity of a good, service, or activity to satisfy a need or provide a benefit to a person or legal entity” (Baier and Rescher, 1969)*

This definition permits the inclusion of avoidance of a loss as a value driver as it provides a benefit to those exposed to the risk of loss. The following sections explore two aspects of value. Performance gaps are a manifestation of the underlying notions of value that influence a DMU’s decisions, shaping their solution space. The following sections explore two dimensions of value that have a bearing on specification behaviour.

### **Dimensions of Value: Financial and Non-financial Value**

Spencer and Winch (2002) present a model of how buildings add value for clients that initially explores the financial value that construction projects bring for clients; arguing that some clients might prefer lower capital cost; others, lower operating and maintenance costs; and yet others value the contribution that a new setting makes to profitability through productivity increases. Under the heading of non-financial value, they discuss spatial quality and indoor air quality. However, these building performances are then linked to productivity and can therefore be

considered a precursor to financial value. This indicates that some functions of value while ostensibly non-financial may be considered to link, in time, to financial outcomes.

Unfortunately Spencer and Winch's (2002) system boundary for discerning value is limited to matters internal to the project. If these system boundaries are expanded to consider the externalities caused by the project, the positive and negative value impacts of the construction project can be seen to affect a significantly wider system than the project organisation. For example, Spencer & Winch do not consider the use of fresh water for construction in drought prone areas, the emission of toxins to land, air or sea, or the noise from construction and operation. These externalities impact on the quality of others' lives, but are not captured in the financial statements of organisations. Reducing these impacts would add value to, and may form the performance objectives for those project stakeholders outside of the narrowly defined project team.

However, as society becomes increasingly aware of, and concerned with, the impacts that organisations' activities have on the environment and society, these external impacts might also shift from being non-financial impacts towards becoming financial impacts. This can happen, for example, through the potential for litigation against the project, or remediation costs for harm caused. The potential for such external impacts to become financial impacts means that they might be more properly described as 'pre-financial'. It is noted, however, that assigning a financial impact to all events can be challenging.

### ***Dimensions of Value: Risk and Opportunities***

In the short term, however, firms deviate from the neoclassical assumptions of profit maximising to gain or maintain competitive advantages, for example, through advertising or research (Garnaut, 2008). From this it is inferred that commercial organisations perceive value in opportunities to enhance long-term profits, or to ameliorate risks to those same profits. Indeed, organisations generally consider future uncertainties in this risk / opportunity manner (see, for example, TCFD, 2016; Trucost, 2016)).

#### ***Risks***

If the future were exactly the same as today, companies would be able to make decisions in an approximately neoclassical manner. However, almost every consideration of the future introduces uncertainty. Risk is defined as the effect of uncertainty on objectives (BSI, 2009), with these effects being a deviation from the expected outcome, positive or negative. Following the early work of Knight (1921: 1964) a distinction is usually drawn between uncertainty and risk: with risk being described as measurable uncertainty. That is: it is possible to assign a probability distribution to the possible outcomes from a risky event – such as the spin of a roulette wheel, or a well understood surgical procedure; but not to one that is uncertain, for which the probability distribution of likely outcomes is unknown, or unpredictable. When introduced to a new scenario, an individual attempts to make sense of it using their previous

knowledge and experience to reduce uncertainty (Appendix D). Over time, and through repeated testing of, or exposure to an uncertain event, the scenario becomes better understood. Outcomes can be anticipated, uncertainty is reframed in terms of perceptions of risk distributions. Uncertainty and risk perception are, therefore, considered to be subjective (Slovic, 2016). While risk can lead to positive outcomes, this thesis adopts the more common use of the word 'risk' as a downside phenomenon; describing positive outcomes of uncertain events as 'opportunities' (see below). Both terms are used to denote varying degrees of subjective perceptions of unpredictability. Securing future profits through the avoidance of risk and uncertainty can be considered to deliver value to commercial organisations (Baier and Rescher, 1969).

### *Opportunities*

Opportunities to enhance long-term profits arise through the development of temporary competitive advantages accruing to organisations through innovation, insight or connections. Such advantages typically arise after investment by an organisation in systems, people or product development. Some of these investments might be protected by intellectual property laws, granting rights over the exploitation of the advantage, reflecting the investment in developing the advantage. However, such temporary advantages are quickly eroded (Aghion and Howitt, 1990), in particular in a highly competitive construction industry in which organisations have the opportunity and motivation to sell their experience into multiple projects. The striving for these competitive gains ultimately renders previous technologies obsolete, resulting in what Schumpeter (1942 : 1976) describes as 'creative destruction'. Firms that fail to react to new technologies that threaten their long-term profit margins often fail as the new technologies gain traction (Christensen, 1997b).

### ***Locating Value***

These dimensions of value have been combined to form the matrix in Figure 52, informed by data points AE, AH, AM, AW and AY, which shows four sectors (sources) of value for an organisation that might result in the appearance of a performance gap in the material specification decision. The matrix can be used to locate the value that project participants attach to an issue, or seek from a project, and proposes a means by which they might be encouraged to invest resources in the projects to overcome material lock-in by promoting NMS on projects.

While the argument supporting investment to secure short- or long-term opportunities for financial gain is relatively straightforward, investing to avoid risks require further exploration. Financial risks represent potential short-term, foreseeable, monetary losses to an organisation; pre-financial risks are those longer term risks that might impact on an organisation in the future, perhaps through reputational damage, poor stewardship, or changes in the operating environment that could restrict the organisation's ability to operate. Pre-financial risks are

considered to have a temporally remote impact on profits and can have the characteristics of uncertainty, rather than risk, that is, there is no certainty over the probability of their occurrence.

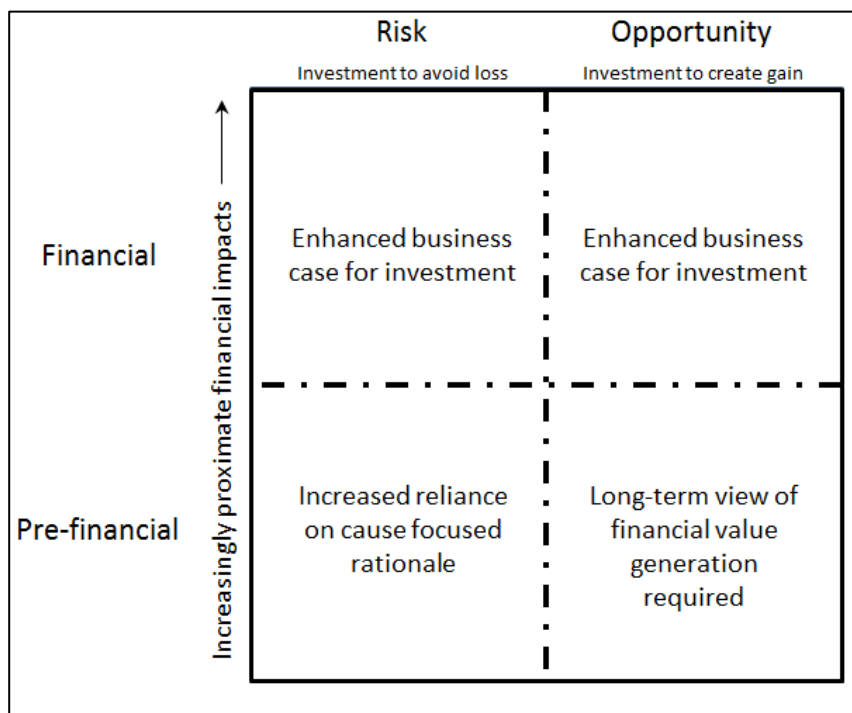


Figure 52 – Dimensions of value. The drivers of investments in value

The extent to which decision-makers and organisations consider these longer term, pre-financial risks and opportunities will depend on their decision-making horizons (Hansson, 2005), that is the timescales and breadth of their decision-making. As investors turn to assessing threats to long-term organisational value resulting from poor environmental stewardship, motivated by their fiduciary duties, these pre-financial risks will receive more attention (data point AY).

The four value sectors are described below:

- **Financial opportunity.** This value sector reflects the value of increasing profits, the objective of many commercial organisations. This might be achieved through a cost-saving measure through the adoption of a process or product innovation, or by enhancing income. This value sector is considered to be the most likely to attract short-term investment due to the direct impact on the primary improvement trajectory of commercial organisations.
- **Pre-financial opportunity.** The value in this sector reflects investment categories that will not have an immediate financial impact. In the short term, these opportunities may appear in pre-financial ways: an enhanced ability to recruit; a marketing advantage; enhanced market perceptions, but they are expected ultimately to result in positive financial outcomes. The timescale and amount of the impact is uncertain.
- **Avoidance of financial loss.** Organisations may seek to invest to address items falling into this sector due to their impacts on short or long-term profits. Examples include matters that might attract litigation or regulation, such as emissions with a proven link to human health.

The investment may take the form of lobbying, hiring lawyers or investing to stop the occurrence in the first place.

- Avoidance of pre-financial loss. Risks in this value sector are not expected to impact on the financial outcomes of the organisation in the short term. However, in time, they may do so through resulting litigation or regulation. As these matters may be the feature of future regulation, there is a possibility that they might move towards one of the other sectors over time, depending on the materiality of the issue and the saliency of the issue in the market's eye. Investments in this sector are long term and uncertain to deliver value. As the risk becomes increasingly proximate, they might be described as 'near financial'

For a given potential source of value for an organisation, there will be a view – implicit or explicit – as to which of these potential value sectors the issue falls. This view, coupled with the strength of the organisation's requirements to demonstrate a financial return will help determine whether or not an investment in a new material receives funding. Pre-financial investments require a longer term view of investment. Due to the multi-attribute nature of construction materials, it is possible that a material can deliver value within more than one of these value sectors, and it may sit in different sectors for different project participants.

At this time, the risks presented by GHG emissions are presumed to sit in the 'pre-financial risk' sector for many organisations in construction. There are other actors, however, whose decision horizons are drawn such that they perceive the risks, or opportunities, presented by the need to reduce embodied GHG, and have begun to consider them in their approach to building (presentation by British Land, data point AL). This indicates that these organisations view the issue as a near-financial risk, or sitting in the pre-financial gains sector.

The engineers wanted to use a 'lightweight' and resource efficient cable-net roofing system to deliver the architect's vision for the project that had been won through competition. At RIBA stage B, the client advisors advised against the scheme because they had a procurement concern – they could foresee hold-up risks, and because the scheme was costed incorrectly at this time, using an inappropriate precedent, the engineering solution was dropped.

### ***Dimensions of Value Explored – Concrete Encasement, Asbestos, Intumescent Paint***

Concrete encasement of steel beams was the primary method of steel fire protection in the early 20th century. This solution to fireproofing is heavy, costly, time consuming and space intensive (steelconstruction.info, 2016).

Asbestos has properties that make it an ideal construction material, and has been used extensively since the late 19th century in many construction applications (The Mesothelioma Center, 2016). The use of lightweight, fireproof asbestos boards to surround steel sections overtook the use of steel encasement in the 1960s. It achieved this as it addressed the drawbacks in the dominant technology, meeting the fire regulations more cheaply, and providing aesthetic enhancements. It presented a number of relative advantages (Rogers, 1995). The

value proposition to the client of asbestos at the time of adoption sat in the financial opportunity value sector. There were other competing technologies, such as intumescent paints, but at that time these were expensive to purchase and apply, presenting a less persuasive business case. The development of these paints continued, however, while asbestos panels were used and became the dominant solution.

As is now well known, asbestos use has significant impacts on health. This created a risk to those using asbestos based products and to the producers and specifiers of asbestos products. The link between asbestos and mesothelioma had not been comprehensively proven in the 1970s, and so the ability to avoid litigation meant that the external impacts were near-financial, rather than financial risks. Accordingly, specification of asbestos continued.

Once the causal link between asbestos and mesothelioma had been confirmed, the possibility of litigation and regulation became much more likely. For those interested in specifying intumescent paints, a value investment opportunity then arose. The continued use of the then dominant asbestos exposed those using and specifying it to the risk of financial loss. The relative cost of intumescent paints had fallen, and the value of their use as a risk avoidance mechanism increased as their use avoided the risk of litigation from using asbestos. Increased adoption of intumescent paints followed.

### **Consolidation: A Synthesis Model**

A recent scenario analysis suggests that if the construction industry fails to respond to the need to reduce embodied GHG in construction materials by up to 67% by 2027 (Giesekam, Barrett and Taylor, 2016). This discussion continues by assuming for simplicity that a drop in organisational value occurs at a single point in time, in 2050, due to the need to invest in the development of new knowledge and skills to deliver low embodied GHG buildings. The cost of doing nothing about embodied GHG reduction, that is the downside risk exposure, can be represented by a point (X) on the graph mapping cost and time (Figure 53 below).

Figure 53 shows a consolidated industry view of the implementation problem in relation to a specific novel material over time. In this figure, the additional cost line is shown as horizontal, reflecting the total evidence costs required for a given technology, as shown in Figure 47 above. Figure 53 also introduces indicative project lifespans for consideration. These are included for time reference purposes and should not be read in connection with the cost axis.

Individuals, and to a lesser degree organisations, view future costs and present costs differently. Costs in the future are 'discounted' to permit comparison with current values. The discount factor reflects, inter alia, an allowance for the time value of money and allowances for the uncertainty of future events. Ellingham and Fawcett (2006) and Garnaut (2008) provide further discussions on the factors affecting discount rates. At the outset, the model presented here assumes that rational decisions in organisations are made using an exponential discount



function, that is, a consistent time preference. Future costs, when viewed after such discounting, fall in value in terms of today's money.

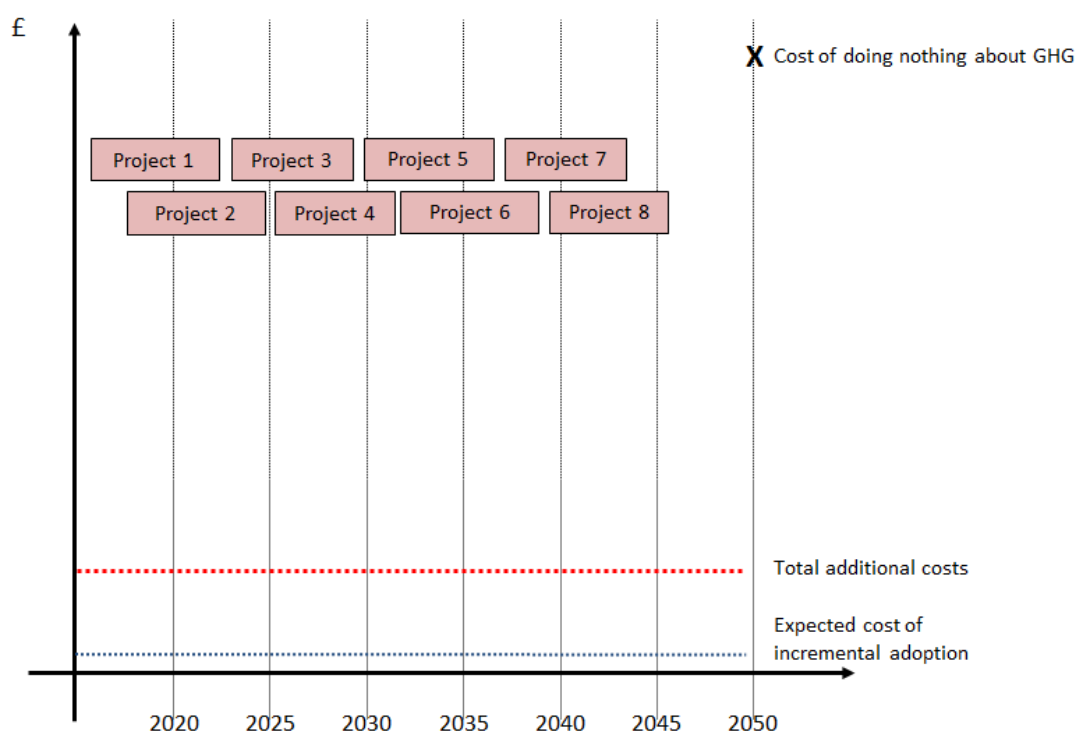


Figure 53 – Industry-wide view of novel material adoption

Figure 54 shows the effects of discounting the cost of 'doing nothing' from 2050 to earlier periods. However, different organisations will adopt and apply different discount rates, reflecting their particular views of the future. Some illustrative discounted costs are shown by the dashed discount lines in Figure 54 below. In this example, company 1 uses a higher discount factor, company 3 a lower one, reflecting the relative importance they attach to future costs. Reading Figure 54 from the origin and forward through time, if a given discounted loss line is below the total additional costs line, the value investment in risk amelioration (the cost of doing something, i.e. investing in the learning etc. that leads to NMS adoption) is greater than the loss avoided through the investment. Until the point at which the discounted loss crosses the total additional cost line, a rational, positive profit seeking company, would choose not to invest to avoid of risk of loss from not addressing GHG. This is because doing so would create a net reduction in shareholder value.

Under this premise, the illustrative discount rates applied in Figure 54 suggest that company 1 would not seek to invest in adoption until approximately 2042 (project 8); company 2, 2036 (project 6); while company 3 would be willing to invest immediately as their discounted loss of doing nothing exceeds the value investment of adopting. If each of these companies were part of the same project, their differing views of the present costs of doing nothing about reducing GHG emissions may lead to conflicting priorities on a project.

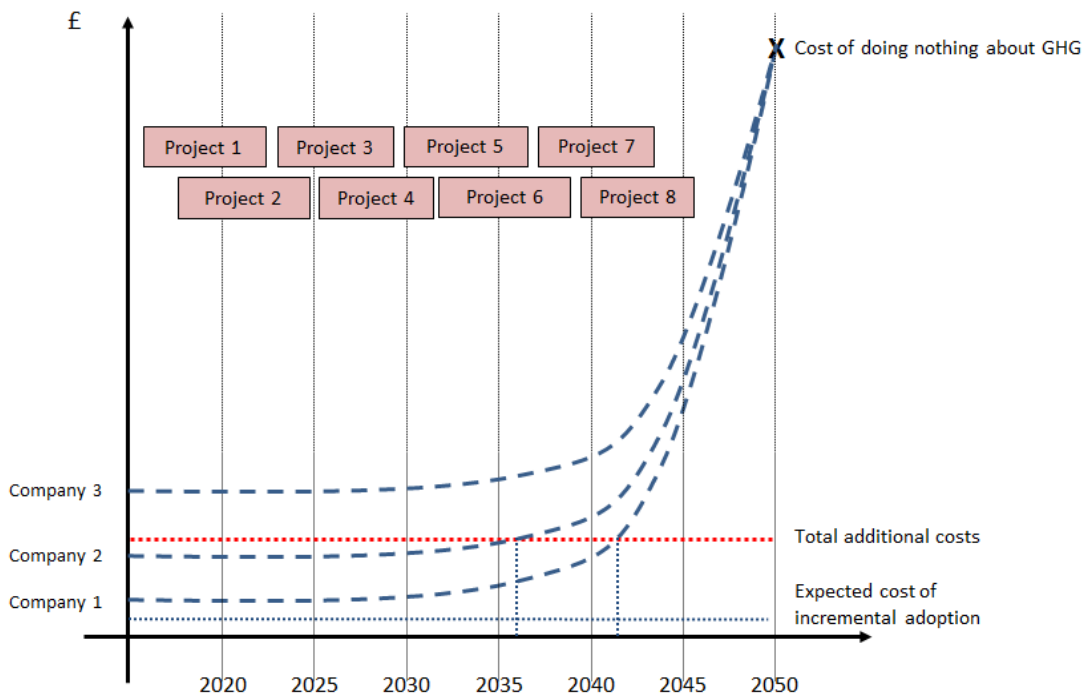


Figure 54 – Industry-wide view: Discounted cost of doing nothing about GHG

If typical life span of a building construction project is assumed to be in of the order of 5 years, six projects will be conceived and completed before the point of adoption is reached for company 1. A consultant attempting to address the temporally remote risk of embodied GHG in the context of early short-term projects for company 1 will probably fail and barriers will be presented as the company will perceive insufficient risk avoidance benefit in doing so.

Figure 54 also includes a line illustrating the possible marginal costs of adopting an incremental, or supportive, innovation (Unruh, 2002; Foxon and Pearson, 2008). As this line falls below the cost of doing nothing for all organisations, the adoption of incremental innovations (as shown) is alluring. Such an innovation might allow GHG emissions to be reduced sufficiently to demonstrate virtuous incremental progress to stakeholders at a given point in time (non-financial opportunity). However, such incremental innovations in dominant technologies will be insufficient to deliver the required total GHG reductions (Allwood et al., 2012). At some time, the investments in skills, knowledge and processes to deliver using new materials in construction will need to be made.

If the early investment costs of company 3 are socialised, the evidential costs and production costs (not shown) will fall (see Figure 55), inducing company 1 to accelerate their adoption to 2026 (project 4) and company 2 to project 1. Reducing residual uncertainty and addressing information hygiene is seen to advance the adoption of novel technologies (assuming, of course, that performance meets the standards required). This view supports the provision of information to project participants proposed by other researchers, but recognises that it may not be sufficient, and that different organisations may have higher burdens of proof / a lower tolerance of residual uncertainty. They will need to be provided with different amounts of

information, and will have differing propensities to invest in learning at a given time. Further, and critically, they will have differing expectations of future events under uncertainty. This demonstrates how the costs of adoption will fall heavily on these earlier adopters, reducing the incentive for them to invest in the data creation: a first mover disadvantage.

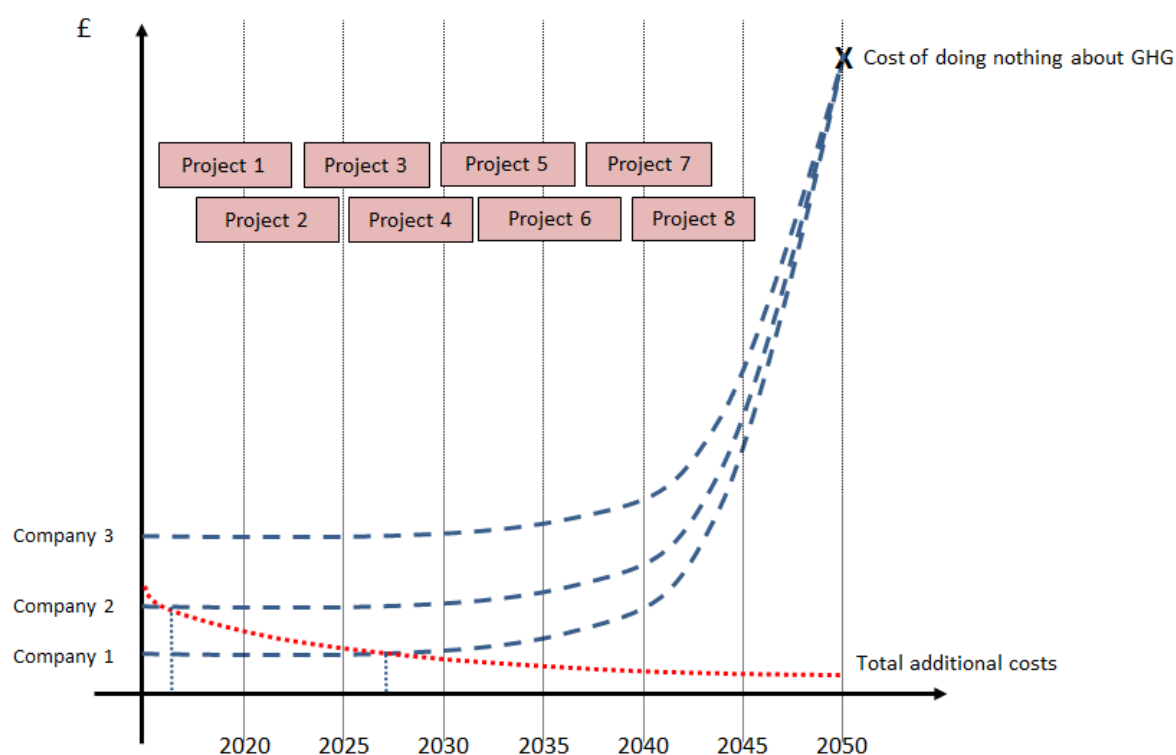


Figure 55 – Adoption profile facing individual organisations reflecting falling evidential costs

### ***Risks to future profits***

The above examples use the risk of loss of market value arising from the effects of the Climate Change Act as a catalyst for investment to avoid losses. This approach has been adopted as the impacts on the organisation's value arise from the common resource can be converted to a future financial risk through the presence of long-term legislation.

Commercial organisations are established to deliver a financial return to investors. Organisational value drivers reflect opportunities to enhance current or future profits, or to ameliorate risks to current or future profits. Climate change and other externalities arising from the use of certain construction materials currently represent pre-financial impacts on many organisations. They do have impacts outside of the company and projects though, and companies are increasingly being held to account, often through the courts, for the impacts of their decisions and supply chains. These externalities, therefore, can all be considered as potential risks that require managing. There are companies, however, that are willing to defer or forego some of their expected financial returns to ameliorate pre-financial impacts.

Large, listed, construction clients, contractors and advisors are required to disclose the strategic risks and non- (pre-) financial impacts of their operations by EU non-financial reporting

regulations (European Commission, 2014) and the related implementations into UK law (The Companies Act 2006 (Strategic Report and Directors' Report) Regulations 2013). Some others choose to publish limited related information for their stakeholder community.

If these risks and related non-financial metrics are considered material to an organisation's future, there is a presumption that decisions at a construction project level would reflect these organisation level risks. Depending on the level of reporting maturity, this company level non-financial risk reporting may, in time, lead to closer management of the impacts of the construction process (Baumgartner and Ebner, 2010). In turn this might deliver an enhanced organisation level value proposition to overcome lock-in through the adoption of unconventional materials at the project level to ameliorate the perceived pre-financial risk.

It is this symmetry of client and project organisation and project level risks that this research seeks to explore.

## **Appendix B – Participatory and Non-participatory Observations**

This appendix presents a summary of the participatory and non-participatory observations and interactions that took place during the course of the research project. References in the tables on the next eight pages refer to the data presented in subsequent pages. Participatory observations are designated with a single capital letter, while non-participatory events, both academic and non-academic have two identifying capital letters. Where no reference has been included in the tables, notes from those events, while taken, have not been reproduced here as they do not add to the narrative discussion in the thesis.

## Participatory Events Undertaken During the Project

Duration (research related)	Description	Reference
20 hours	Review of Materials databases / Construction materials database tools design requirements elicitation	A
15 hours	Exploration of alternative materials for textile factory in India	B
10 hours	Granta / Cambridge KTN steering committee input.	C
20 hours	Opportunities for NMS use on live college project	D
3 hours	Managing energy reduction in a college environment – development of a tool.	E
35 hours	Exploring opportunities for glass re-use	F
7 hours	Review of Materials Efficiency Metric for infrastructure project	G
3 hours	Brick v timber assessment of GHG impacts for new building	H
4 hours	Study of open innovation models	I
14 hours	Planning for presentations: <ul style="list-style-type: none"> <li>• Future Cities – context values and appropriate material choice</li> <li>• UKGBC Cities Conference, Manchester.</li> <li>• Delivering small scale, high quality retrofit</li> </ul>	-

Duration (research related)	Description	Reference
2 hours	The Restorative Neighbourhood project workshop.	-
35 hours	North Sea oil and gas rig decommissioning and re-use opportunity report	J
7 hours	(Confidential project)	-
14 hours	Foam Ceramic	K
14 hours	Circular Economy - paper on residual value	L
5 hours	Sustainability opportunity sessions: School project / SIG / Perth	M
3 hours	Orkneys Bio-Economy report (limited)	N
20 hours	Get it Right Initiative	O
1 hour	Sustainability workshop	P
1 hour	Meeting to discuss developing with CLT in South Africa and the UK	Q

233 hours

In addition to these specific events, the researcher has 5 years' experience of working in the industry as architectural technologist and BIM manager. This experience, and research time spent in the sponsors' office, has also informed the reflections presented in this work.

### Industry Focused Events Attended During the Research Project in Which Field Notes Were Taken

Event Type	Date	Location	Title	Reference
Conference	08/10/2013	London, UK	ASBP – Mainstreaming Sustainable Products: Beyond the Green Guide	AA
Seminar	11/11/2013	London, UK	RAEng – Innovation in Materials.	-
Seminar	23/01/2014	London, UK	UCL ISR – Un-burnable Carbon	-
Conversation	21/02/2014	London, UK	Discussion with Sustainability Advisor, Forum for the Future.	AB
Lecture	07/04/2014	London, UK	Grantham Institute Annual Lecture – Unilever's Project Sunlight: Sustainable Growth: Paul Polman	AC
Lectures	29/04/2014	London, UK	The Concrete Centre – Innovating with Ferrocement	AD
Seminar	01/05/2014	London, UK	CBRE – Show me the Value! The Value in Sustainable Construction	AE
Seminar	16/06/2014	London, UK	UCL ISR – New Environmentalism and the Circular Economy	-
Presentation	19/11/2014	London, UK	IStructE – Innovation in the WWF Head Office.	AF
Seminar	25/11/2014	London, UK	UCL ISR – The UK's Low Carbon Pathway to 2030	AG
Workshop	05/01/2015	London, UK	The Crowd – The CFO's Dilemma	AH
Seminar	28/01/2015	London, UK	ASBP – Embodied GHG as an Allowable Solution	-
Telephone call	26/03/2015	-	USGBC – Regional Credits in LEED	AI
Seminar	Ecobuild	London, UK	Ecobuild – Various talks	AJ
Seminar	07/05/2015	London, UK	The Concrete Centre – Concrete, BREEAM and the Home Quality Mark	AK



Event Type	Date	Location	Title	Reference
Presentation	22/09/2015	London, UK	Sir Robert McAlpine – ‘Building a Better Future: Our Journey’	-
Workshop	01/10/2015	London, UK	UKGBC – Embodied GHG : Action and Implementation	AL
Webinar	05/10/2015	London, UK	IEMA – Communicating Value Creation Through Natural Capital to the Mainstream	-
Seminar	19/11/2015	London, UK	Supply Chain Sustainability School – Understanding a Client's Need to Build Sustainable Homes	-
Presentation	28/01/2016	London, UK	CDSB – Comply or Explain: Review of FTSE 350 GHG reporting in annual reports	AM
Lecture	11/04/2016	London, UK	Grantham Institute Annual Lecture – Christiana Figueres	AN
Seminar	19/04/2016	London, UK	Property Week – Spotlight on Sustainability: How do we Defuse the Eco Time Bomb	-
Seminar	26/04/2016	London, UK	Max Fordham – Sustainable Housing - Beyond the Bonfire	-
Seminar	28/04/2016	London, UK	Sturgis Carbon Profiling – CE in Construction	-
Workshop	2015 / 2016	Berlin, Milan	Ellen MacArthur Foundation Acceleration Workshop	AO
Talk	16/11/2016	London, UK	UCL Lancet Lecture 2016 – Christiana Figueres; Action on climate change for a healthier world – putting the Paris Agreement into practice	AP
Talk	19/11/2016	London, UK	R&D Society event – ‘Not invented here!’ R&D in Construction	AQ
Discussion	21/12/2016	London, UK	Informal conversation about an innovative project	AR
Talk	13/01/2017	London, UK	Will McDonough – Cradle to Cradle, the Circular Economy, and the New Language of Carbon	-

Event Type	Date	Location	Title	Reference
Talk	20/01/2017	London, UK	Circular Economy thinking in Construction Conference	AS
Meeting	16/02/2017	Camberley, UK	Observation of Board Meeting: Discussing Innovation in Construction.	AT
Workshop	22/02/2017	London, UK	How will the Circular Economy impact concrete manufacturing businesses?	AU
Seminar	14/03/2017	London, UK	AECOM – How do we Meet the Global Resource Challenge?	-
Workshop	28/03/2017	London, UK	UKGBC – Delivering the Sustainable Development Goals	AV
Conference	04/05/2017	London, UK	GRESB – Siemens Spring Conference : Leading Sustainability Innovation for Real Estate	AW
Webinar	08/06/2017	-	Carbon Trust – Science Based Targets	-
Webinar	26/09/2017	-	UKGBC – Delivering Low Carbon Infrastructure	AX
Conference	15/11/2017	London, UK	Bloomberg Sustainability conference	AY
Discussion	25/07/2018	London, UK	The Hoffman Centre, 'Reinventing the Building'	AZ

### Academic Events Attended During the Research Project in Which Field Notes Were Taken

Event Type	Date	Location	Title	Reference
Seminar	25/03/2014	London, UK	UCL - Behaviour Change and Sustainability	-
Book Launch	06/05/2014	London, UK	UCL - The Behaviour Change Wheel - A Guide to Designing Interventions	-
Conference	04/11/2014	London, UK	UCL Urban Sustainability and Resilience Conference	-
Seminar	15/06/2015	London, UK	UCL Institute of Advanced Studies: Interdisciplinary thinking	-
Conference	09/06/2015	Santander, Spain	WASCON – Resource Efficiency in Construction	-
Conference	08/03/2016	Hamburg, DE	Sustainable Built Environment Conference 2016 – Strategies, Stakeholders, Success Factors	-
Conference	20/04/2016	London, UK	UCL Construction Technology – Road Mapping the Next 5-10 years.	BA
Conference	18/05/2016	Salford, UK	Construction – Building a More Sustainable Future	-
Conference	07/07/2016	Cambridge, UK	Centre for Industrial Sustainability Conference – Capturing Sustainable Value	BB
Talk	15/03/2017	London, UK	Goldsmiths College – Rethinking Capitalism	BC
Conference	18/04/2017	Bath, UK	IASBE 2017 – Creativity and Collaboration (Mixed academic / industrial focus)	-
Conference	23/06/2017	London, UK	Bartlett Doctoral School of Construction and Project Management Conference.	-
Seminar	03/10/2017	London, UK	Prof Roger Levitt (Stanford) Bartlett CPM, Rethinking Infrastructure	BD
Seminar	04/10/2017	London, UK	Prof Roger Levitt (Stanford) Imperial College, Swimming Across Lanes: Addressing Barriers to System-Level Innovation in the Construction Industry	BE

Type: Participatory	Date: Q4 2013	Reference: A
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Review of Materials databases on behalf of the sponsor organisations.</li> <li>• Construction materials database tools design requirements elicitation;</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The acquisition of new awareness, information and knowledge to inform decision-making is a time intensive exercise. The industrial sponsors wished to improve their knowledge management as it related to materials, and to be well informed on the latest materials. This exercise was brought about by the belief that there is a 'best' material for a given task and that the availability of a suitable dataset would allow specifiers to readily identify that best material. The desire for a database indicates that the cost of search is limiting search of that 'best' material.</p> <p>This exercise set out to develop an understanding of the market place for information and the costs associated with collating and maintaining the data to inform decision-making. The specification and review process for the development of the knowledge repository identified that the data needed for decisions vary across the project life cycle from generic, average, data at the outset of the project through to highly specific product data for the final decision points.</p> <p>This view coincides with the discussions that took place at the SBE16 conference in Hamburg on the future of LCAs. Delegates were divided between the requirements for detailed, product specific information on which to make decisions or generic material information that can be used at the early stages of the design process. Any satisfactory solution would need to address both of these requirements to be helpful as the project's specification became more certain.</p> <p>This required search, storage and maintenance of two types of data for use across the project life cycle, both of which would be costly. Therefore, it was judged that the data collation and maintenance cost would be too great for the value derived which could be derived from the availability of the data. A search was then undertaken to identify whether a suitable materials database was already in existence.</p> <p>A review of 38 available on-line databases showed that no single database provided the information and functionality to meet <i>all</i> of the needs in the organisation, at all stages of the design process. While some did show promise, the costs of these systems was considered to be prohibitive for an SME.</p>		

The proposal to develop an in-house data set was placed on hold as the time costs of development and maintenance was considered to be too high.

While many such databases were available, each was created for its own purposes. None covered all of the requirements of the sponsors. This showed that the notion of a 'best' material was highly subjective, context specific, complex, and multi-faceted. Was it aesthetic? Technical? Cost? Sustainability? Do LCAs and EPDs provide us with all of the information we need?

This exercise also highlighted a difference in perspective between the project stakeholders – the use of NMS could be conceived of as being other than sustainable. The novelty in the material could result from a design decision.

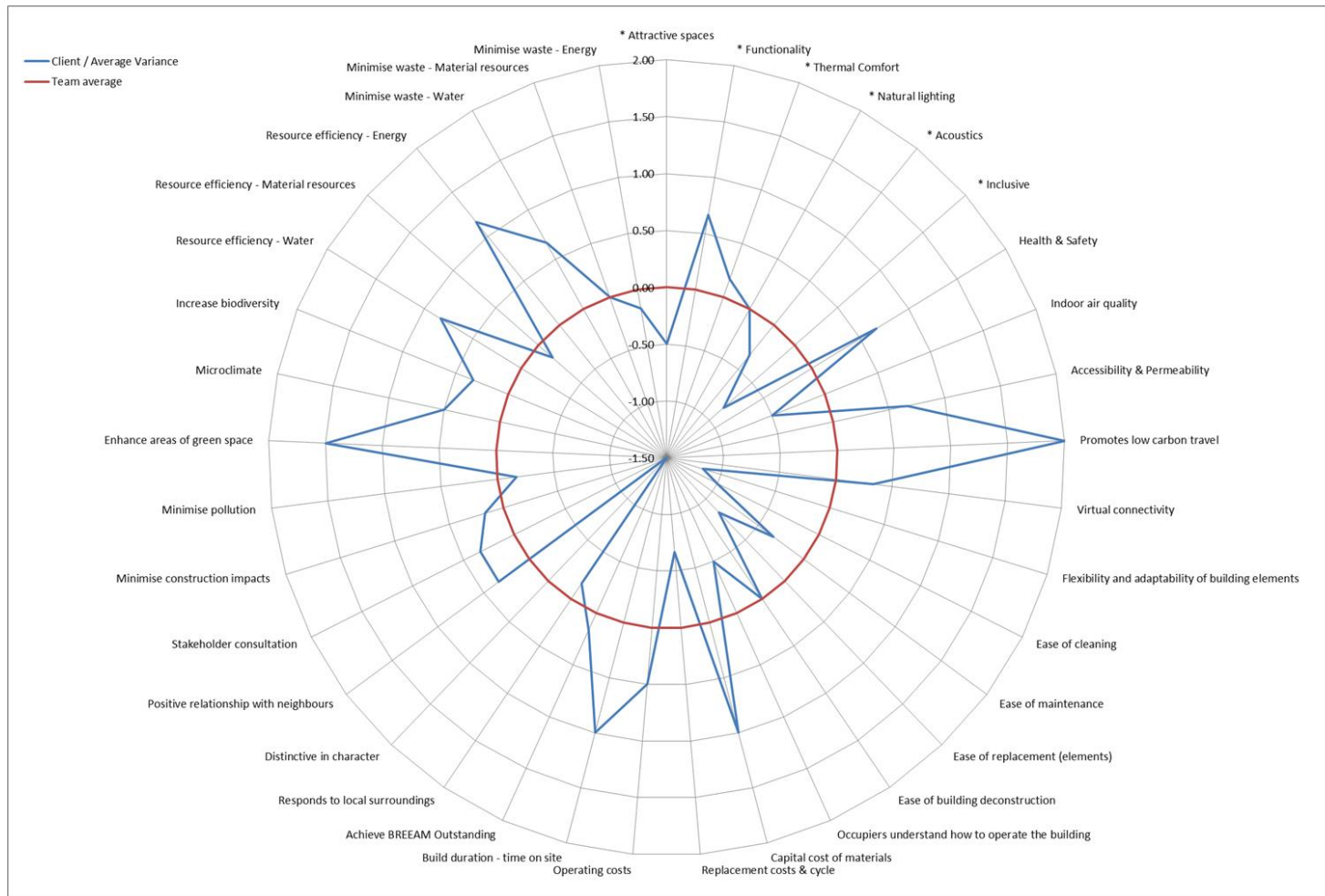
It also opened the door to an exploration of MCDA approaches to material selection, based on these databases (including work by Mike Ashby at Granta). However, the approach taken by Granta looks at the level of the physical material, and not the product. This distinction is important as product manufacturing processes are location, time and process specific. Only by developing an all-encompassing database including all products with up to date information can one begin to identify what might be best.

Type: Participatory	Reference: B
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Exploration of alternative materials for textile factory in India. The client had significant aspirations to be the most ecologically sound textile factory in the world. Much work was done on water, materials, waste and air quality.</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>This early project set out to explore the options for NMS on a construction project in India. Work centred on exploring local materials, and the relatively cheap costs of labour, compared to the costs of material.</p> <p>Despite the client being very keen to deliver a sustainable building with the lowest impact materials at the outset, <i>the budget had been fixed at an early stage of the planning</i>, setting project cost and time expectations at a level comparable to a 'typical' solution. This effectively precluded the NMS identified during the search from the specification solution space, leaving those tried and tested solutions.</p> <p>However, a GHG study was undertaken and it transpired that due to the weight of machinery involved that the single biggest contributor to embodied GHG in the project was the foundations. These were then optimised. Clearly in this research, sustainability meant lower GHG, at the same price. The materials research on the project was funded by the consultants from their fees.</p> <p>The outcome was that the project went ahead with limited NMS due to the budget requirements to be 'at least as cheap and quick as' the dominant solution. A small display area was constructed using NMS.</p> <p>Here embodied GHG was seen to be an improvement trajectory, rather than performance gap.</p>	

Type: Participatory	Reference: C
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Granta / Cambridge University KTN steering committee input.</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>This steering committee brought together academics and industrialists interested in promoting resource efficiency and the advancement of software supporting efficient material selection.</p> <p>The role of trade suppliers in encouraging the uptake of EPDs, requiring that their suppliers provide them, encouraging uptake to move the market for information. This shows an encouraging amount of foresight from the retailer.</p> <p>The Steering group explored the challenges of developing a dataset of products rather than materials; a reliance on the manufacturers and data quality issues. The aim was to develop early stage tools that would permit conceptual designs to be tested. Again this highlighted the differing data needs at the various stages of the process as the degree of detail and specificity for the materials/products increased as the project went through time.</p> <p>Things are not static on construction projects, information needs evolve over the course of the project, starting with the generic ('cladding'), through to the specific ('curtain walling'), and the branded ('Schüco glazed façade system')</p>	

Type: Participatory	Reference: D
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Materials workshop for a new education building.</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>A workshop was run by the researcher in which key project participants on a new university building project were challenged on their material choices for the project – proposing NMS in lieu of the dominant solutions adopted. Participants from the different PBOs (client, architect, structural engineer, M&amp;E etc.) was asked to provide a rating of the importance of design decisions on life cycle stages and impacts in accordance with the University's own sustainability assessment scheme. The results were summarised and compared using a radar diagram and heat map (see below)</p> <p>The workshop highlighted the starkly differing views of the project participants as to the importance of the different life cycle stages and, as well as the assumptions made by the participants as to what was important in the material choice decision to meet client needs. The summary figure below shows how the project team views of motivators (collated) differed from the client's.</p> <p>The assessment led to a discussion about the client concerns, opening the door to further consideration of less impactful materials, with potential solutions being provided by the researcher. The intention was to align the solution spaces of the various specifying DMUs around the client's sustainability requirements, and to populate the solution spaces with solutions that address these performance objectives.</p> <p><i>This study demonstrated two important factors: that project participants have differing concerns over what is important in the construction project; and how framing conversations on the client's interest and drivers of value can steer project teams towards more value-aligned solutions.</i></p> <p>However, while the workshop provoked insight and discussion, it was <i>ultimately unsuccessful in encouraging the specification of NMS on the project due to the timing of the intervention</i>. Much work had already been completed by the consultants, decisions had been made as to their resource commitments to the project, and early specification decisions had informed later design decisions. The consultants were reticent to begin a process of re-work that might be futile and simply reduce the profitability of their work.</p>	





Radar Diagram Comparing the Relative Importance of Client Sustainability Criteria to the Team Average Perception

			Weighting						
Sustainability Themes	Weighting	Specific Objectives	Material production	Material transport	Construction	In-Use	Maintenance	Renewal	End of life
User experience	Inspiring Learning Spaces	Quality of spaces:							
		• Attractive spaces	20	12	8	20	8	16	16
		• Functionality	25	15	10	25	10	20	20
		• Thermal Comfort	20	12	8	20	8	16	16
		• Natural lighting	20	12	8	20	8	16	16
		• Acoustics	15	9	6	15	6	12	12
	Wellbeing	• Inclusive	10	6	4	10	4	8	8
		Health & Safety	20	12	8	20	8	16	16
		Indoor air quality	15	9	6	15	6	12	12
	Accessible & Connected	Accessibility & Permeability	20	12	8	20	8	16	16
		Promotes low carbon travel	20	12	8	20	8	16	16
		Virtual connectivity	15	9	6	15	6	12	12
	Futureproofing	Flexibility and adaptability of building elements	15	9	6	15	6	12	12
	Good Functionality & Easy to Maintain	Ease of cleaning	15	9	6	15	6	12	12
		Ease of maintenance	20	12	8	20	8	16	16
		Ease of replacement (elements)	15	9	6	15	6	12	12
		Ease of building	15	9	6	15	6	12	12
	Whole Life Value	Occupiers understand how to operate the building	15	9	6	15	6	12	12
		Capital cost of materials	20	12	8	20	8	16	16
		Replacement costs & cycle	15	9	6	15	6	12	12
		Operating costs	25	15	10	25	10	20	20
Local issues	Distinctive place	Build duration - time on site	20	12	8	20	8	16	16
		Achieve BREEAM Outstanding	20	12	8	20	8	16	16
	Community	Responds to local surroundings	15	9	6	15	6	12	12
		Distinctive in character	10	6	4	10	4	8	8
		Positive relationship with neighbours	20	12	8	20	8	16	16
	Enhanced Ecology	Stakeholder consultation	15	9	6	15	6	12	12
		Minimise construction impacts	15	9	6	15	6	12	12
		Minimise pollution	15	9	6	15	6	12	12
		Enhance areas of green space	20	12	8	20	8	16	16
		Microclimate	15	9	6	15	6	12	12
	Efficient use of resources.	Increase biodiversity	10	6	4	10	4	8	8
		Resource efficiency - Water	20	12	8	20	8	16	16
		Resource efficiency - Material resources	20	12	8	20	8	16	16
		Resource efficiency - Energy	25	15	10	25	10	20	20
		Minimise waste - Water	15	9	6	15	6	12	12
		Minimise waste - Material resources	15	9	6	15	6	12	12
		Minimise waste - Energy	15	9	6	15	6	12	12

Heat Map Highlighting the Percived Importance of Life cycle Stages in Delivering Client Sustainability Outcomes

Type: Participatory	Date: 23/6/2016	Reference: E
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Managing energy reduction in a college environment – development of a tool, review meeting.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>In developing a decision-making tool, simplicity and the reduction of choices parameters available was considered to be key. This supports the simplified LCA approach, but would only work for this client as the simplification would reflect their value drivers.</p> <p>The pursuit of BREEAM ratings was driving decisions on new build. It is the metric on which the client bases their reserved design decisions. Material choice has very little influence on BREEAM scores.</p> <p>When developing the business case stage for low-energy developments (stages 1-2) the client stakeholders are only interested in the running <u>costs</u> of the buildings as these influence their day to day lives. The capital costs are someone else's problem. Energy is not widely considered. This tool is an attempt to facilitate an easy consideration of different design options life-cycle GHG</p> <p>There is a need to engage people with energy and GHG before budgets are set. <i>Timing is critical.</i></p> <p>Cost and payback are the key drivers for estates management. This client is concerned to ensure that GHGs in use shouldn't increase. GHG <b>in use</b> is therefore a limiting factor, acting as a constraint on decisions rather than embodied GHG.</p> <p>Sustainability is always the last item to be considered in meetings.</p>		

Type: Participatory	Date: Q4 2013	Reference: F
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Exploring opportunities for glass re-use in response to a Defra ITT on the circular economy.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>An exploration of the potential for increasing the 'circularity' of a building product was undertaken on behalf of a <i>listed</i> material manufacturer once funding had been secured for the project from a Government fund. The exercise involved a review of the financial and embodied GHG savings that could be made by the recovery and remanufacture of existing products on removal from buildings under renovation or demolition.</p> <p>The review found that GHG savings could be made, and a business case was produced to support the GHG case for action. Once completed, the client expressed relief that the business case had also demonstrated viability as <i>without a supportive business case the project would not have proceeded</i>.</p> <p>Saving GHG was considered to be a good thing from both a PR perspective and longer term risk avoidance – the company would be required to purchase 'carbon credits' in the future. However, GHG reduction in itself was insufficient to motivate behaviour change if this caused production costs to increase. The changed process needed to be at least cost neutral to make changes. Sustainability is all well and good as long as it doesn't affect the bottom line.</p> <p>The Government tender documentation described how innovation can be new to the world (invention); new here; new retro or new to you. This highlights how innovation is subjective.</p>		

Type: Participatory	Reference: G
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Review of Materials Efficiency Metric for infrastructure project</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>This infrastructure project seeks to “<i>source and make efficient use of sustainable materials, maximise the proportion of material diverted from landfill and reduce waste.</i>” A metric was developed to aid the organisation to influence contractor behaviours to meet this objective.</p> <p>The metric is – in effect – a simplified weighted LCA, meeting the needs of the organisation and driving the behaviours that they seek.</p> <p>The metric was considered to have the potential to influence designers and contractors at the point of procurement, despite it not being associated with any financial sanction or incentives (reflecting an improvement trajectory, rather than expectation or requirement for the project). Assessment of the metric would be incorporated into a range of other non-time/cost metrics that could be used to assess the contractors.</p> <p>As with embodied GHG in buildings, there is a vital need to create benchmarks against which the actual performance can be assessed. It would have to be specific to the needs of this type of project. These should link, somehow, to the GHG emissions that are permissible in the UK. Failure to link these two items risks an overshoot on GHG budgets as everyone endeavours to ‘do their best’ without understanding what that needs to be.</p> <p>The baseline could be set as current best practice, to allow room for innovation to improve on current best practice.</p>	

Type: Participatory	Reference: H
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Brick v timber assessment of GHG impacts for new building</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>A client project was keen to understand which of two alternative cladding solutions had the lowest embodied GHG emissions. The research task was to provide a comparison between the two.</p> <p>Data was sourced from the 'ICE embodied carbon' calculator that uses generic embodied GHG data. The process of calculation was found to be highly problematic, and required many assumptions leading to the results being heavily caveated. In particular:</p> <ul style="list-style-type: none"> <li>Data quality was poor (but the best available): <ul style="list-style-type: none"> <li>No LCA information was available for either solution;</li> <li>The data was historical, reflecting old production techniques;</li> <li>While the geographical source of the data was provided, no adjustment was possible to reflect differing energy mixes in the production process;</li> </ul> </li> <li>The requested limitation of the study to a functional unit of 1m<sup>2</sup> of the external skin of the façade ignored the supporting structures and joining materials that would have had a material effect on the outcome. System boundaries are important;</li> <li>No account was taken of the delivery to site and end of life impacts. The comparison was very limited.</li> </ul> <p>Ultimately, the data was accepted with the caveats. There was limited interest in exploring the problem further due to a lack of project budget.</p>	

Type: Participatory	Reference: I
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Review of open innovation models for a presentation by a director</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>Open innovation refers to processes of innovation that step outside of the traditional organisational boundaries to increase the inflows of knowledge. This increase in knowledge through the ‘crowdsourcing’ of ideas broadens the perspectives that can be brought to bear on a problem, accelerating the process of innovation and improving the outcomes.</p> <p>A parallel can be seen between this process of open innovation and the use of early contractor engagement and integrated product delivery, where experience and ideas from different PBOs are made available to designers at an early stage of the project influencing design decisions. This early integration of ideas avoids unnecessary re-work as performance objectives are introduced later, or normatively better outcomes are available to the project using other PBOs’ knowledge and experience.</p> <p>It is notable that many organisations in construction remain within the traditional linear models when innovating for fear of the loss of competitive advantage and investment.</p>	

Type: Participatory	Reference: J
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• North Sea oil and gas rig decommissioning &amp; re-use opportunity workshop and report</li> <li>• The project involved the identification of possible uses for end of life oil platforms and involved a Delphi-style workshop to identify and critique opportunities for re-use.</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>The re-use of materials is restricted by the quality of the material and the conformation of that quality. The reverse logistics process is 'a value kill'. Price, quality and performance is all important (performance requirements), and it is not acceptable to have significant underlying uncertainty about these new / re-used materials.</p> <p>Larger organisations may be more likely to explore this as they have more scope (slack) to do so.</p> <p>The uptake of re-use requires a big-win early on to show how it can fit into BAU (visibility). It also requires a coherent market into which to sell the product. The cost of the product needs to be acceptable (comparable price).</p> <p>Sometimes an increase in cost is not the issue – it is the hassle factor (effort, time); people don't want to disrupt the efficiency of the supply chain. We also see this with the steel fitting on site – (Moynihan and Allwood, 2014) on steel over use. Effectively making it about cost and time.</p> <p>When encouraging the adoption of new solutions, the path of least resistance should be followed – make it as easy as possible for the product to be bought – simplicity. This links with Rogers' adoptability criteria.</p>	



Type: Participatory	Date: Q4 2013	Reference: K
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Foam Ceramic. The sponsors were asked to become involved in the testing of a new foamed ceramic material created by an architect.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Attempts were made to engage the material producer with University researchers who might be able to provide testing equipment for a newly created material. Formal testing routes had proven to be prohibitively expensive for the material creator.</p> <p>As a new member of the college, the researcher didn't have the network or knowledge to understand where they should be taking their material for testing.</p> <p>It demonstrated the importance of networks, knowledge, and the challenges and costs that new material producers face when trying to get their materials onto the market with little financial backing.</p> <p>This echoes the problems faced by ModCell who have spent many years trying to get their product tested and certified (referred to in data point 9)</p>		

Type: Participatory	Reference: L
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Circular Economy - paper on residual value</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>In advancing material re-use – a form of NMS - a life cycle analysis of the material is important to ensuring that users can identify the value proposition in re-use.</p> <p>A construction client was exploring the business case for re-use and had requested a paper summarising how life cycle assessment might fit into the business case.</p> <p>The production of the paper highlighted the challenges in developing a business case around the re-use of materials due to the long timescales involved in the life of construction assets. For long-life assets, the value of constituent materials at end of life is both highly uncertain, and when discounted to the point of investment, typically negligible. Assessing financial opportunities in such circumstances proves challenging, highlighting the need to focus on the opportunities to avoid downside risks when making the business case.</p> <p>This paper highlighted the commercial imperatives in typical construction projects and the challenges of change in a short-termist environment.</p>	

Type: Participatory	Reference: M
<p><u>Brief Description:</u></p> <p>Sustainability Opportunity Sessions</p> <ul style="list-style-type: none"> <li>• SIG</li> <li>• School project</li> <li>• Perth</li> </ul> <p>The aim of these sessions was for a team external to the project team to look at projects and identify and propose opportunities to enhance the sustainability of the project, typically after the initial design work had been completed. The client team would then be asked to discuss these with the team.</p>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>Perth: All changes would be subject to a cost-benefit analysis. However, the key performance expectation for the project is space – the development agreement <i>requires</i> a net area be delivered. Changes from this figure are deviations and costly. Subsequent drivers are construction speed and a PBO drive for material efficiency - this had been linked by the PBO to the need for space savings. All proposals for NMS needed to be driven by and respond to this key driver and were <i>subject to a 5 year pay back requirement</i>.</p> <p>The implementation of the SOS outcomes was entirely dependent upon the project leader. Some were less willing to introduce sustainability concepts to projects as they were outside of their scope of work, others were 'more disruptive' and likely to step outside of their scope to effect change – highlighting the importance of the individual's commitment to NMS specification, and the contingent nature of success.</p> <p>Respondent from the sessions suggested that the sessions happen too late to effect change – too much had already been settled. They also complained that – as structural engineers – they have little influence in the decision-making process relating to the sustainability of the overall project. They have to convince ('get buy-in from') the architect, or the client that a change is desirable. From this it is inferred that it is considered to be outside of the scope of structural engineers to consider sustainability. That they do so might be considered scope creep, despite the ideas being appropriate for the project.</p>	

Type: Participatory	Reference: N
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Orkneys Bio-Economy report. The Orkney Islands are looking to enhance resource efficiency and are exploring ways that they can promote a symbiotic bio-economy. This report was produced to begin the discussion and promote innovation towards the development of the bio-economy.</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>Industries and operations have developed over time to do what's best for themselves within their own system boundaries. This occurs everywhere, highlighting the influence that the company as separate legal entity has over economic activity.</p> <p>This report is an attempt to stimulate an intervention that will encourage a more holistic view when making decisions – a step towards re-integration. This is much needed in construction. It is clear that the individual decision makers are unlikely to make the changes without an external stimulus or support.</p> <p>Change requires the application of effort from the academy, industry and government. Demonstration projects, proofs of concept, capacity building are all key to the adoption of new processes for the greater good: reducing uncertainty, costs, and waste and creating jobs. It is interesting that the whole project has been couched in socio-economic terms.</p>	

Type: Participatory	Reference: O
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Get it Right Initiative: a study of re-work in the construction sector. This study was driven by the recognition that the industry wastes much time and effort in re-work. It arose from conversations a director of the sponsors was having with contractor contacts, trying to understand what was driving them.</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>The study showed that waste was high, around 20% and that contractors considered the elimination of waste <i>would help them to shore up their bottom line</i>. At the moment, an allowance is made for re-work. If this could be reduced, they could <i>gain a competitive advantage</i> when bidding for new work.</p> <p>However, it became clear that any competitive advantages created by the elimination of waste would only be temporary, and that it would, in time, be eroded by other firms adopting similar strategies. The advantages gained by eliminating the waste would ultimately be passed to the client, the key beneficiary of improved efficiency.</p> <p>The study also highlighted the contractor focus on trying to reduce costs &amp; thereby survive. There was no talk of taking the market with them through innovation. It was all about cost, and any references to innovation from them revolved ultimately around reducing costs (or improving time / buildability / H&amp;S).</p> <p>This study aided the identification of two important elements for the study</p> <ol style="list-style-type: none"> <li>1) Optimised planning leads to a lack of slack in the construction project – if things go wrong, it has big knock-on impacts.</li> <li>2) The tendency in the market to conflate the sector when discussing innovation and change.</li> </ol>	

Type: Participatory	Date: 29/9/2015	Reference: P
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Sponsoring office sustainability workshop. Exploring the Sustainable impacts that the organisation has had and can have on projects</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Drivers for successful innovation are various &amp; vary by project: Social (Athens, Tensegrity, WWF), resource base (earth bricks not used, but earth labyrinth), economic (extending life of building)</p> <p>Where they tried &amp; failed</p> <p>They're often "<i>not even around the table</i>" when key decisions are being made so are unable to influence them. Their performance objectives are not reflected in decisions and are therefore attempts to incorporate them may lead to sanction.</p> <ul style="list-style-type: none"> <li>They intervened too late - key decisions have already been made that preclude the use of NMS on projects.</li> <li>Procurement schedule blocks some more interesting solutions – the evidence that is need to support the new solutions takes time to find or generate. That time buffer is not generally available on projects as timelines have already been established assuming the use of DMS. The use of NMS is therefore seen to risk the timely completion on projects.</li> <li>The projects were too cost restrictive – budgets had already been set that preclude the use of NMS.</li> <li>Only one supplier of the solution in question - this is a common response – a hold-up risk from asset specificity, potential impact on delivery.</li> <li>A reticent market place from prior experience</li> </ul>		

Type: Participatory	Date: 25/08/2017	Reference: Q
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Meeting to discuss developing with CLT in South Africa and the UK.</li> </ul> <p>The researcher was approached to convene a meeting between UK practitioners, researchers and visiting academics to discuss the challenges and opportunities for building with CLT in South Africa.</p>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>In SA architects want to use CLT, but clients aren't open to the risk (uncertainty) at this time. The key problem is considered to be a lack of an evidence base of performance in the SA context (information deficit); the QS also seems to be an obstacle.</p> <p>The reason the UK is permissive is because of the way our building control system works – it is results focused rather than being prescriptive. To convince clients you need to describe the commercial and performance benefits of the product. Many of the savings don't come from the product, they come from the process, and that is where the QS puts their 'bunce'. The QS (in SA in particular) doesn't have sufficient knowledge of the building process to judge the savings correctly.</p> <p>Policy can be a barrier – people will argue that <i>"if I don't have to do it, I won't"</i>. Timber is frequently considered <i>"guilty before being proven innocent"</i>.</p>		

Type: Non-participatory	Date: 08/10/2013	Reference: AA
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• ASBP Conference Mainstreaming Sustainable Products: Beyond the Green Guide</li> <li>• This was a gathering of those with an interest in the promotion of sustainable building products.</li> <li>• The event took place in the first month of the research project.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>It's important to look at products, not materials. You can have the same product with different materials. The impacts from different suppliers of products will change over time, and space.</p> <p>One supplier proposed that suppliers go out and “...<i>find your niche and work it.</i>” This was a reference to Rogers’ model of technology diffusion.</p> <p>Architects and designers over specify products for the budget, leading to losses through VE. This indicates that designers may have drivers other than costs that they are seeking to deliver on the projects. When contractors take those over-specified products out to achieve the cost targets, it is often leads to client disappointment.</p> <p>There was a discussion on the nature of regulations: are they intended to raise the floor – the base level of performance, or to raise the ceiling – making the best better. In terms of embodied GHG, we need to do both!</p> <p>ModCell experience of costly certification and the hurdles you have to jump through. Who is going to fund their investment?</p>		



Type: Conversation	Date: 03/10/2017	Reference: AB
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Discussion with Sustainability Advisor from Forum for the Future</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Businesses are in the market place to compete for market share. Some elements that they face, such as GHG, should be considered to be pre-competitive, that is it is in the common interest to address these problems rather than leaving them to the market to compete over. Key to making this shift is to bring all of the actors together – a challenge in such a dispersed industry – and agreeing what it is they’re going to do about it.</p> <p>They have done a similar exercise for the shipping sector.</p> <p>From an infrastructure perspective they explored culture related issues. They came to the conclusion that although there are some genuine barriers to doing new things (including using new materials) like finance structures, actually these were always conquered by the more firms with an innovative culture. Effectively, where there is a will, there is a way.</p> <p>They looked at how the space in which you work can affect your mind-set (and lock you into the usual way of doing things) and how this might be changed (framing); how facilitating / holding key meetings differently can inject some creativity and shift the balance of power in team from the ‘dinosaurs’; and how you can harness the creativity and ideas from remote workers, as ideas from the coal face can often be ignored by HQ.</p>		

Type: Non-participatory	Date: 07/04/2014	Reference: AC
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>Grantham Institute Annual Lecture : Unilever's Project Sunlight: Sustainable Growth: Paul Polman</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Paul Polman has led their charge to halve Unilever's environmental impact, taking a leadership positions in the drive to do so. Sustainability for Unilever is about more than doing good. It is a protection against future, emergent trends. They are willing to invest today to secure their future. It's <i>also</i> about doing the right thing; one of the founding principles of the company was about improving conditions in Victorian Britain.</p> <p>The change can be delivered in Unilever as it originates from the CEO, who had support of the organisations shareholders. This highlights the role of top-down initiatives in creating change.</p> <p>An interesting after note - Unilever's investment in the future meant that there were current opportunities to save on costs and increase short-term profits by stopping that investment. In 2017 a cost cutting private equity group made a bid for Unilever. The bid though, was short lived, as the board understood the business model and strategy. Mr. Polman is quoted in the FT say that the bid was "<i>clearly a clash between a long-term, sustainable business model for multiple stakeholders and a model that is entirely focused on shareholder primacy.</i>" (Daneshkhu and Barber, 2017)</p>		

Type: Non-participatory	Date: 29/04/2014	Reference: AD
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• The Concrete Centre: Innovating with Ferrocement</li> <li>• This presentation described the innovations that occurred in the development of the solar canopy of the SNFCC in Athens.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The process of innovation is a negotiation. Everyone needs to buy into the proposal; the process could have been stopped by any of the project team with a veto.</p> <p>Much of the work that the engineers did during the implementation phase (post search and selection) revolved around them convincing themselves that they had a suitable solution for the project (validation). The process they went through once a potential solution had been identified included:</p> <ul style="list-style-type: none"> <li>• A search for precedents</li> <li>• Review of existing design guidance</li> <li>• Study the precedents</li> <li>• Discuss the issue with specialists</li> <li>• Prototyping and testing (done in part to convince others)</li> </ul>		

Type: Non-participatory	Date: 01/05/2014	Reference: AE
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• CBRE: Show me the Value! The Value in Sustainable Construction</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Value is not just financial value; there are other notions of worth. However, this session focussed mostly on the former. Further, the emphasis was clearly on the use phase of the building's life cycle, rather than the construction phase.</p> <p>Most activity in the construction industry is risk based. What are the reasons for 'going green'?</p> <ul style="list-style-type: none"> <li>• Reward (short-term opportunity)</li> <li>• Reputation (long-term opportunities)</li> <li>• Risk (avoiding loss)</li> <li>• And it's the right thing to do (long-term loss avoidance)</li> </ul> <p>Typically investments in technologies on buildings must be able to demonstrate a 5 year payback period.</p> <p>The premium of building sustainably (LEED Platinum) is 1%, this is dwarfed by the operational savings.</p> <p>The inability to let out lower (energy) rated buildings due to regulation is forcing people to pay attention. Buildings are being upgraded or divested. The market isn't seeing a push from occupiers. The demand for sustainable buildings can't be assumed to be there.</p> <p>Regulation has a role to play in setting trajectories, but policy makers don't understand quite how slowly the industry moves. There is a need for a consistent and stable trajectory from government – there is a concern that Government won't maintain their course. This reduces any incentives for long-term investment.</p> <p>Sustainable buildings are now shown as being more profitable. It's more likely that those that aren't are being sold at a discount.</p> <p>Energy in performance is the major talking point across this talk. There was a chortle when bees &amp; bugs were mentioned.</p>		

Type: Non-participatory	Date: 19/11/2014	Reference: AF
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Presentation Innovation in the WWF Head Office.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The client, a charity concerned with preservation of nature and wildlife were designing their new headquarters.</p> <p>The charity was concerned to ensure that the building reflected their concerns, and that it trod lightly as far as its social and environmental impact was concerned. As a result, the client specified – early in the project – that the building should meet a number of specific criteria, including pursuit of BREEAM outstanding.</p> <p>This early definition of project requirements and expectations allowed an integrated design approach to be pursued to gain the maximum benefits.</p> <p>A ‘carbon’ audit was undertaken, with an initial budget being set based on the planning consented scheme. However, the speaker described this initial budget as being based on relatively typical assumptions, and not reflecting the state of the art specification at the time. However, incorporating embodied GHG into the client’s requirements documents for delivery led to a reduction in embodied GHG of 42% on this baseline, showing the importance and influence of the client in addressing the problems of embodied GHG.</p>		

Type: Non-participatory	Date: 25/11/2014	Reference: AG
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>UCL ISR - The UK's Low Carbon Pathway to 2030</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>This talk centred on the transition progress being made in the UK towards the low-GHG economy. The speaker highlighted a number of technologies that are gaining traction – e.g. LED lighting, EVs, PVs. Many of these examples are like for like switches, requiring little or no changes in use behaviour at the point of use. They are also directed at in-use energy performance</p> <p>That these technologies are ‘crossing the chasm’ suggests that Rogers’ 5 criteria of adoptability have relevance to the implementation of new technologies in construction. :</p> <ul style="list-style-type: none"> <li>comparability</li> <li>simplicity</li> <li>observability</li> <li>trialability</li> <li>relative advantage</li> </ul> <p>In this circumstance, the roles of comparability, simplicity and observability are prominent.</p>		

Type: Non-participatory	Date: 05/01/2015	Reference: AH
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• The Crowd: the CFO's Dilemma</li> </ul> <p>The Crowd is a B-Corporation that seeks to encourage the shift to more sustainable business models. They create forums and events that explore the economic system for market failures. This event was to explore the tension between the strong short-term pressures facing CFOs and the recognition that long-term value is increasingly being determined by societal trends?</p>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The starting point for businesses is financial value. It's not always possible to engage customers in sustainability – it's not considered to be a differentiator in the market place.</p> <p>Companies that don't invest now won't survive in the longer term.</p> <p>The big wins happen when engineers get creative and identify new solutions to new problems.</p> <p>In FMCG it is very hard to capture the value of waste through a reverse logistics cycle as the product is of low initial value and highly dispersed.</p> <p>If a proposal for change doesn't deliver financial value, it won't happen.</p> <p>There is a need to convince shareholders that <i>sustainability is part of a longer term resilience strategy</i> to deliver long-run dividend stability or growth.</p> <p>GHGs are currently more of a reputational risk than a financial one.</p>		

Type: Conversation	Date: 26/03/2015	Reference: AI
<u>Brief Description:</u> <ul style="list-style-type: none"> <li>USGBC: Regional Credits in LEED</li> </ul>		
<u>Notes, Observations &amp; Insights</u> <p>The role of assessment schema to deliver 'sustainable' buildings is limited as the underlying assessment and scoring methods do not take into account the entirely context specific conditions. The US has started to address this by overlaying weather maps / population densities / urban v rural info onto their rating scheme. However, the ability to scale that is limited. They are hoping to explore overlaying population growth models and future climate models to the LEED scheme to enable the development of resilient buildings.</p> <p>Questions arising:</p> <p>How do you deliver location specific rating schemes? Why should you? CEEQUAL was held out as allowing for this response by requiring the project team to explore the context in a more rigorous manner and respond to that exploration.</p>		



Type: Non-participatory	Date: 2015	Reference: AJ
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Ecobuild talks (2014 / 15)</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Contractors typically pitch 10-15% below what it costs to build and then steal the profits from others in the supply chain: Clients in a strong market, supply chain in a weak market.</p> <p>Innovation in construction is often negatively compared to car manufacture. Ship building is a better analogy given the scale and site bound nature of the process.</p> <p>Issues:</p> <p>Workmanship; knowledge; fragmentation; lack of knowledge from the building control enforcement people are all stopping Low GHG retrofit;</p> <p>Builders merchants have a vital role to play, but they're the last people that builders turn to. The (perceived) customer perspective on lowest value is important as people don't do a good job. How do we fix it?</p> <ul style="list-style-type: none"> <li>• Perhaps environmental assessment should be part of the planning application (Arguing for a form of regulation).</li> <li>• Link to Council tax bills – financial (dis)incentives.</li> <li>• Minimum performance requirements on exchange for sales.</li> <li>• Mortgages attach to energy efficiency</li> </ul> <p>No one got sued for oversizing, or over delivering. There is a risk of litigation for underspecifying, no significant downside for over specifying or over ordering as long as you are within budget.</p>		

Type: Non-participatory	Date: 07/05/2015	Reference: AK
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>The Concrete Centre: Concrete, BREEAM and the Home Quality Mark</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The HQM is a new voluntary scheme to replace the code for sustainable homes. HQM focuses on delivering quality for the end user. The scheme is not being enforced by councils (and the government have since regulated to ensure that it explicitly cannot be) the uptake was likely to be (and has proved to be) limited. While the scheme itself is actually quite well considered with its focus on what the homebuyer actually wants from the house, the scheme is likely to be an 'unconsidered variable' for the major housebuilders due to the lack of requirement.</p> <p>You need to think about sustainability to the outset to ensure you get good credits.</p> <p>Concrete can be used to get good BREEAM ratings: the example given was the use of concrete bird boxes put in to achieve ecology credits. This was possibly a low point in the research.</p>		

Type: Non-participatory	Date: 01/10/2015	Reference: AL
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• UKGBC: Embodied GHG : Action &amp; Implementation</li> </ul> <p>This was a one day conference promoted by the UKGBC to encourage a focus on the issues of embodied GHG and to stimulate action.</p>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Mission based drivers are stimulating some clients to think about this, but it typically descends into a conversation about metrics, and percentages. Getting in early (including with suppliers) is crucial in cutting embodied GHG significantly. There were lots of examples of good practice happening elsewhere in Europe, particularly the NL, Germany, France. These were all government led agendas.</p> <p>Many spoke of a desire to have regulation (this is a common complaint heard across events). UK is behind on embodied GHG (especially now government support has been removed/reduced).</p> <p>Embodied GHG is a fringe issue. Client uptake/interest/understanding is limited and this is limiting progress. Clients don't want to talk about GHG – it's always a cost discussion. ROI must be 2/3 years. The Infrastructure group are now saying by rote that GHG reduction is cost reduction to promote this agenda.</p> <p>RICS are taking a lead in this area and looking to develop standard. Need to have benchmarks, targets and stretch targets – but what's the baseline for a particular building? How can we know how it relates back to the requirements of the climate change act? Current lack of benchmarks is major barrier to uptake on mass. Some tools are available, but they are by generic building type. We need a 'baseline building' akin to that in Part L of the building regulations. If the data isn't available, the matter simply isn't considered.</p> <p>Some developers interested – British Land, Landsec, Argent – but it is driven by enthusiastic individuals, not the organisation. Argent sustainability team tried to get embodied GHG into employers requirements for their Kings Cross development, but struggled. There was no buy-in at higher levels of the organisation (DMU decision variables). Recommendations for establishing an embodied GHG brief:</p> <ul style="list-style-type: none"> <li>• Include targets in the brief</li> <li>• Be clear on the benefits</li> </ul>		

- Optimisation should be done before tendering - this is a critical point on timing.

British Land has been asked by investors & SRIs about their scope 3 emissions. Therefore, they have set a company-wide benchmark (arbitrarily set at 20% reduction, 50% was considered too much of a stretch). The target was achieved on one project with a slight change to the external cladding. Marginal change: big gains. But they don't know if it's enough.

Type: Non-participatory	Date: 28/01/2016	Reference: AM
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• CDSB: Comply or Explain: Review of FTSE 350 GHG reporting in annual reports.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Environmental factors should be considered as risks, not KPIs. They tend to be managed as KPIs. Scope 3 reporting is limited, and was described as an indirect benefit to an organisation rather than the direct impacts of reducing scopes 1 &amp; 2. Investors don't look beyond the company boundary. There is a clear distinction between what companies can influence and what they are held accountable for.</p> <p>Reporting serves two functions, to provide information to the market, and as a stimulus to discussion at board level.</p> <p>Materiality is a key concern – GHG reporting should be based around the reasons why GHG is NOT material to the business rather than why it isn't.</p> <p>In practice, SAB Miller concern themselves with both risk mitigation and value adding aspects of sustainability. These are the drivers of investors and stakeholders, both internal and external.</p> <p>SAB Miller's investors generally not that interested in the PRI's Montreal Pledge - a commitment by investors to annually measure and publicly disclose their portfolio's GHG footprint. <b>Their concerns are more whether they are compliant with regulation, and whether risks are being effectively managed.</b></p>		

Type: Non-participatory	Date: 11/04/2016	Reference: AN
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Grantham Institute Annual Lecture : Christiana Figueres</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>There is a directional relationship between meeting the SDGs and the climate needs. All SDGs have to be achieved in a low GHG manner. The SDGs have a social, economic and moral urgency. With climate, however, there is also an in built physical urgency.</p> <p>There is little slack in the system to get to the objectives. Time is not our friend. The longer we delay, the more dramatic the fall to net-zero at 2050.</p> <p>This imperative is urgent, no time to waste. The insurance industry has said that increases above 2 degree will mean that the planetary system becomes uninsurable.</p> <p>Policy or physics will lead to stranded assets</p> <p>Three reasons why things look positive:</p> <ul style="list-style-type: none"> <li>• Lots of capital looking for a return</li> <li>• Infrastructure needs lots of investment – roads and homes to last</li> <li>• Cheap money is plentiful</li> </ul> <p>Historically, governments have jump started economies by massive investments. It's now time to do it again with low GHG investments.</p>		

Type: Non-participatory	Date: 2015 / 2016	Reference: AO
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Ellen MacArthur Foundation Acceleration Workshop (Milan, Berlin)</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Messages around fail / fast fail well are encouraging early &amp; fast niche adaptation, ensuring that new products mainstream sooner rather than later.</p> <p>Many large FMCG were represented, and their key focus was on the reverse logistics and whether their material impacts have the potential to disrupt their operations going forwards.</p> <p>Construction attendee highlighted the role of deconstruction of assets not in terms of resource efficiency, but as a way of keeping in touch with the client over the building life. This is not altruism. There's a long-term financial opportunity.</p> <p>Manufacturing is qualitatively different from construction in terms of process change.</p>		

Type: Non-participatory	Date: 06/11/2016	Reference: AP
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• UCL Lancet Lecture 2016 –Christiana Figueres</li> <li>• Action on climate change for a healthier world – putting the Paris Agreement into practice</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The reduction of GHG is a process, it will get harder over time. Paris sets a path and a destination point (a ‘net-zero carbon’ planet in the second half of the century). Acting on climate change is less expensive than not acting (in the long term, subject to certain assumptions).</p> <p>Climate change is too abstract – translate the effects of Climate change to more mundane factors: for example, health.</p> <p>Paris is looking at the supply side – it isn’t unleashing the power of demand. As soon as we get individuals saying we don’t want any of this high embodied GHG product, companies do change. When young people look for jobs these days, they are looking for organisations that have similar values, and environmental values are one of those being sought out. Companies will have to respond. Companies should share their science based plan. The C-Suite is listening.</p> <p>If they want the crème de la crème working for them, they have to be more responsible. Individuals have a lot of power. Individuals have a lot of power.</p>		



Type: Non-participatory	Date: 09/11/2016	Reference: AQ
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>R&amp;D Society event 'Not invented here!' R&amp;D in Construction</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Construction R&amp;D is not formalised and coordinated. It is not well understood how it happens and how knowledge is shared.</p> <p>The complexity of interests in the supply chain means that these must somehow be aligned to ensure that innovation happens. Specifiers want to innovate, but it falls out when we get closer to the money. There is a fear of 'what if we get it wrong', 'what will our investors say'. Advice to sell the commercial aspects first before any sustainable attributes.</p> <p>Industry doesn't share privately acquired knowledge. Not sharing is not a construction issue alone, but the long gestation period for new knowledge is. Professional bodies have a role in disseminating new knowledge, bringing academia and industry together. Stories don't get written up – there's no time or budget for that. Risk takers should fail fast &amp; fail well. Niches should work together. But do we have the appetite? Undercapitalised small manufacturers cannot afford to take the risks.</p> <p>In infrastructure Innovate18 shared knowledge across contractors and sites very successfully. These learnings are now being transferred to HS2 and the Thames tideway. How is this incentivised? Risk reduction, benefit sharing.</p> <ul style="list-style-type: none"> <li>Research is about de-risking innovation.</li> <li>There is a problem with stability in supply, and similarly, intermittent demand.</li> <li>First and foremost clients want predictability – on time &amp; on budget</li> </ul> <p><i>"If you want a revolution, you have to address the client"</i>. The scoping of projects is often sub-optimal for innovation: the system boundary determines the outcomes. Innovation is risk – if you do something new you might get fired.</p> <p><i>"our job is to do the best for our shareholders. If shareholders don't want us to innovate, we won't"</i></p>		

Type: Conversation	Date:21/12/2016	Reference: AR
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Discussion about a completed project that had an innovative element.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The project design was selected through an architectural competition.</p> <p>The PM appointed was experienced in fit-outs, but wasn't competent (lack of prior experience) to deal with the scale of the works required by the winning competition entry.</p> <p>The project manager's role was to fix the time limits on the project. They were optimistic that the project would be completed on time, in part because the scope of works had been fixed (a staircase should be built). However, the design had not yet been concluded. The engineer argued that not enough thought had gone into defining the scope of works and therefore the time line for the project could not be settled.</p> <p>Lots of PMs would have got it wrong as they had failed to understand the complexity of the client's requirements for the stair case (largely through their inexperience). Ultimately, however, the staircase was not on the critical path and didn't impact the project delivery date.</p> <p>The QS was less optimistic – they were required to fix the costs. They wanted a 'cheap and cheerful' solution to get the overall project back on budget. The innovative staircase hadn't been included in the original plans, and therefore budget. It caused the total cost to exceed that budgeted, but provided the client with the value they sought.</p> <p>The project was self-funded by the client through the sale of another property.</p>		

Type: Non-participatory	Date: 20/01/17	Reference: AS
<u>Brief Description:</u> <ul style="list-style-type: none"> <li>• Building Centre : Circular Economy thinking in Construction Conference</li> </ul>		
<u>Notes, Observations &amp; Insights</u> <p>Making change in construction takes determined leadership, engagement, involvement and collaboration. You have to begin with the end in mind, you must have an intention to innovate.</p> <p>Organisational business plans tend to last around 5 years, but they get refreshed every year (Skanska).</p> <p>There is no silver bullet for adoption, every product has to go through its own journey. But every proposal has to be commercially viable. Re-use (for example) doesn't happen because it's more expensive than buying new. This is due to the economies of scale, and the cost of the re-manufacturing processes.</p> <p>BAM: if a client is sensitive to long-term environmental drivers of value, then the environmental aspects of the material choice can go into the business case for specification. But it has to start at the business model. There is no one solution that works for all, you have to start from scratch each time, looking at the individual client value needs.</p> <p>BAM had a client who wanted to <i>experiment</i> with the circular economy, they wanted to create a learning impact and to influence others. Early contractor and supply chain involvement was key to making the change.</p> <p>Vertical integration of supply chains reduces transaction costs.</p> <p>Availability / Uncertainty of supply constrains implementation.</p> <p>The Information burden is a barrier to market entry / penetration.</p>		

Type: Non-participatory	Date: 16/02/2017	Reference: AT
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Observation of Board Meeting at a main contractor (NN)</li> <li>• Discussion relating to Innovation in Construction</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Q: Does the industry do innovation, or is it just solving problems? The framing of this question reflects the wide conflation of actors with hugely disparate roles in the sector. No attempt was made to discern which aspects of the industry were being discussed.</p> <p>A lack of time, skills &amp; funds retards change.</p> <p>If an engineer has an idea, it is almost impossible to implement. Contractors say they'll do innovation, but don't because it costs more and increases risk. But this is because if the client refuses to pay for (invest in) innovation, it won't happen. However, defensive strategies are adopted in the face of regulatory change.</p> <p><i>"Construction is not in the product business. We're a process business".</i></p> <p>NN accept that they may not be thinking ahead. The water sector was held out as a good example of an industry trying to make it work. However, they're regulated. Those who set standards are part of the alliance seeking to deliver change. It is interesting to note that NN mentioned that Anglian Water self-insure via a captive insurance company, as did t5.</p> <p>NN's process of delivery means that they won't go beyond standards, so that they can't get sued. This sets a range of acceptable performances for a given attribute</p> <p>Vertical integration tends to end in a mess as NN aren't in control of the final delivery standard.</p> <p>There was no discussion about the upsides of innovation, because the downside will wipe us out. <i>"There is a fundamental fear of getting it wrong"</i>. Everything is written around the concept of 'perform or bust'. <i>"If you start taking risks, the organisation's immune system kicks in"</i></p> <p>Other examples discussed: an innovation proposed at Heathrow saved money over a more traditional solution to a problem, but it took many weeks before the locked-in solution could be dismissed as inadequate: eliminating it from the solution space. The British Antarctic proposal (Halley) for walking buildings was dismissed as too capital intensive (expensive). Halley failed because the client didn't fall in love with (adopt) the</p>		

design idea. The money was also fixed limiting scope for creative solutions that required validation.

You have to sell the value of an innovation to a client – you need to get the story straight. Also, having a strong advocate on the client side is important.

When NN make savings from getting it right, they *“give it all away – people wouldn’t recover the 10%, they would compete it away. If waste is reduced, then outturn prices fall, not tender prices. They don’t price to get it wrong, they assume it will go right.”*

*“It’s a competitive advantage to win a job, we put all the savings in to win the bid”* Any saved money gets burnt, defrayed away in the delivery.

*“Improvisation and problem solving is the burning platform for innovation ...”*

The problem in our industry is a lack of trust

Addressing the incomplete nature of project design when it gets to the client, KJ proposed increasing design completeness prior to tender. EM: Contractors hate it as it gives them nowhere to go on a design & build – they should do these contracts through traditional procurement.

NN: When doing new things, we go up the learning curve and then keep doing that – it’s efficient. If it’s complex, it’s a continual sequence of learning curves. We should say to clients that we’re going to train for 9 months. How do you take the learning curve off the critical path? Do we give ourselves enough time?

### Reflections

Site based training needs to be efficient and fast. This limits what you can teach people. It is typically through learning by doing that people gain experience.

This links back to the delegation of tasks and decision-making. If a task is routine, then it can be delegated, but the individual needs to revert to the supervisor for each anomaly. In construction, can they spot these?

A core problem though is that the contractors don’t necessarily have direct line oversight on the operatives, or they are transient operatives on day rates not incentivised to stick their heads up.

There is a role for the last planner on site. Also more robust visualisation exercises.

Type: Non-participatory	Date: 22/02/2017	Reference: AU
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• How will the Circular Economy impact concrete manufacturing businesses?</li> <li>• This was a workshop for a global cement production company looking at the impact of the CE on their future business model.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>To enable change in the market, there needs to be a confluence of external and internal circumstances.</p> <ul style="list-style-type: none"> <li>• Finance needs to be available</li> <li>• There must be a willingness to collaborate</li> <li>• There must be a policy environment that is supportive of that change.</li> </ul> <p>Making it happen:</p> <p>Companies need to develop a route map for long-term change, allowing for the delivery of demonstration projects that will support the overall objective. If policy change is required, the route map should also deal with how buy-in at a policy level can be achieved.</p> <p>People like to see facts and figures – you have to sell the benefits in a language that they understand. 'It makes common sense' just won't do.</p>		

Type: Non-participatory	Date:28/03/17	Reference: AV
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• UKGBC workshop – Delivering the Sustainable development goals. Intended to introduce participants to the SDGs and understand how their organisations can influence their achievement.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>The SDGs is a global framework for delivering sustainable development. Its aspirations need to be tailored to individual organisations country / context.</p> <p>Why adopt an SDG based approach to business?</p> <ul style="list-style-type: none"> <li>• SDGs help to define strategy and purpose</li> <li>• Competitive advantage through a coherent (non-financial) value proposition</li> <li>• Creating shared values across the globe</li> <li>• Creates purpose and builds trust in and between organisations</li> <li>• Avoids criticism of greenwashing</li> </ul> <p><i>“We always get asked about the business case: Better business, better world.”</i></p> <p>60 key opportunities are included in a report; the risks addressed provide organisations with <i>resilience against future changes</i>.</p> <p>Personal and professional commitment to delivery is a key resource in delivering change towards the SDGs.</p> <p>From a contractor: <i>“The priority is not to get prosecuted”</i></p> <p>One participant in the workshop described how they were not delivering on some of the SDGs. They were diverting resources to those areas which delivered more business (financial) benefit.</p>		

Type: Non-participatory	Date: 04/05/2017	Reference: AW
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• GRESB (The Global ESG Benchmark for Real Assets)</li> <li>• Siemens Spring Conference: Leading Sustainability Innovation for Real Estate.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Innovation focuses on the role of the owner: Investors provide the capital, tenants occupy the building and drive the market with their requirements. It is the owner's role to deliver on the expectations of these two stakeholders.</p> <p>The Paris COP21 conference crystallised the risks of climate change. There are two types of risk now facing us (see also TCFD):</p> <ul style="list-style-type: none"> <li>• Transition risk – how will the rules change? How will supply chains change?</li> <li>• Physical risk – increased potential for damage, increased performance requirements for the building stock due to changing temperatures.</li> </ul> <p>Pension funds are starting to ask questions about their long-term fiduciary duties. It's uncertain they really understand them. Discounted cash flows don't capture these longer term uncertainties. But this is about the long term and survival.</p> <p>An investment manager presented his position on sustainability and was very frank: <i>"How much do I think about sustainability? Not very much. Until there's a clear link between sustainability and [financial] value, I won't change that view".</i></p> <p>Due to the long and fragmented chain from investors through owners, managers, vendors to industry bodies, there is a disjoint when it comes to addressing the ESG issues around buildings. Everyone relies on the others to look at it.</p> <p>One speaker highlighted the differing perspectives around the directors table, in particular, the very distinct views of the heads of sustainability (heads will roll if we don't...) and finance (heads will roll if we do...).</p>		



Type: Non-participatory	Reference: AX
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• UKGBC Webinar – Delivering Low Carbon Infrastructure</li> </ul>	
<p><u>Notes, Observations &amp; Insights</u></p> <p>Ways to move things along on infrastructure:</p> <ul style="list-style-type: none"> <li>• Assessment schemes (creating opportunity)</li> <li>• Engage the supply chain (aligning motivations, populating solution spaces)</li> <li>• Make the reputational case (long-term risk of loss)</li> <li>• Make the business case (financial value opportunity)</li> <li>• Early supplier engagement (populating solution spaces, aligning motivations)</li> <li>• Use of performance requirement rather than prescriptive specifications</li> </ul> <p>We need to demonstrate the value of low-GHG solutions.</p> <p>Better knowledge sharing reduces search, validation and acceptance costs. However this is a problem as private organisations like to keep information that they've gathered privately for competitive advantage, Also, the site based nature of construction makes knowledge management problematic.</p> <p><u>Enablers of the transition</u></p> <ul style="list-style-type: none"> <li>• Strong government signals (context requirements or expectations)</li> <li>• A coherent approach across the sector. (establishing network effects)</li> <li>• Implementation of shadow pricing on projects - as has been done in BREEAM NL.</li> </ul> <p>Without some form of rationing, the use of a common good will always exceed the carrying capacity.</p>	

Type: Non-participatory	Date:15/11/2017	Reference: AY
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Bloomberg Sustainability Business Summit</li> <li>• A gathering of those interested in sustainable business, covering the value chain from finance to delivery.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Sustainability has long been considered to be about the impact of the company on the environment, but we are now seeing a switch to consider the effects of the environment on the company, and a company's ability to react to those changes. The TCFD recommendations encourage companies to explore and disclose these risks. This will increase the visibility of longer term climate risks on company valuations, creating an investment opportunity to address embodied GHG by avoiding that future risk of loss.</p> <p>Investors want companies that create value in the long term, but it is all about the bottom line. <i>"We are moving towards a position where companies' GHG disclosures will be audited, so companies are beginning to prepare for that moment now"</i>. Pension funds are looking at who will make the transition well to the new low-GHG economy (i.e. no stranded assets) and who is resilient to future scenarios.</p> <p>The growth of the green bond market suggests that the resource of 'finance' – often cited as a barrier to adoption – should be less of a concern going forwards.</p> <p><i>"With the hardening of policy, uncertainty becomes risk"</i> Ian Simm.</p>		

Type: Non-participatory	Date:25/07/2018	Reference: AZ
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Hoffman Centre for Sustainable Resource Economy</li> <li>• Panel debate at Chatham House on reducing the embodied GHG in construction.</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>During the debate, the framework presented in Chapters 8 and 9 was successfully used to locate the interventions being proposed by panellists. It was evident that all of the interventions discussed were to either create performance gaps (initiators) at the client level, through the introduction of regulation or incentives to promote the use of low embodied GHG material; or to reduce the elaborating impacts (relative disadvantages) of the use of NMS on construction projects (enablers). This could be achieved either through financial support for the producers of or projects adopting NMS, or by removing the cost relative advantage of the DMS through GHG/Carbon taxation (Pigovian tax) – a form of government intervention. This requires the government to ‘pick winners’ which it is reluctant to do.</p> <p>A proponent of CLT stated that <i>they</i> use it because of its GHG impacts, but that clients love it because of its impact on costs, time and site logistics. Clients get their money back sooner.</p> <p>A key quote from the head of the UKGBC “<i>the valuers and agents are looking backwards, not forwards</i>”. Their comments reinforce the argument proposed in Chapter 8 that the use of historic data to inform decisions limits the ability to implement NMS on projects.</p> <p>NMS supplier quotes:</p> <ul style="list-style-type: none"> <li>• “<i>we have to compete on cost, quality and scale</i>”</li> <li>• “<i>Historically, the domestic market has been an early adopter of new technology. Maybe because its very client driven and they know what they want.</i>’ ... ‘<i>the drying time on site works less [well] with commercial schedules</i>”</li> </ul>		

Type: Non-participatory	Date: 20/04/2016	Reference: BA
<u>Brief Description:</u> <ul style="list-style-type: none"> <li>UCL Construction Technology Workshop - Road Mapping the Next 5-10 years.</li> </ul>		
<u>Notes, Observations &amp; Insights</u> <ul style="list-style-type: none"> <li><i>"Construction doesn't do disruptive innovation".</i></li> <li>Clients have the interest, and drive innovation. Contractors are the delivery vehicle.</li> <li>Canary wharf as client encouraged their suppliers to develop innovation as part of their business as usual. But they didn't want them to go too far 'off piste'. Looking for the 'Goldilocks' zone of just enough change.</li> <li>A slow lead in to the market reduces the disruptive nature of a product, preparing industry participants for the new technology gradually.</li> <li>The supply chains in construction are complex and fragmented.</li> <li>Different organisations have differing speeds of uptake of new technologies.</li> <li>Sub-contractors don't want to specify new materials as their professional indemnity is at stake.</li> <li>On-site testing is valuable to move things along on a project.</li> <li><i>You need to have money and time on a project to be able to do innovative things.</i></li> <li>Those who invest in technology development want to retain the IP over it to maintain their competitive advantage.</li> </ul>		

Type: Non-participatory	Date: 07/07/2016	Reference: BB
<u>Brief Description:</u> <ul style="list-style-type: none"> <li>Centre for Industrial Sustainability Conference: Capturing Sustainable Value</li> </ul>		
<u>Notes, Observations &amp; Insights</u> <p>CSR used to be about managing risks, keeping ahead of Greenpeace and the Guardian. The M&amp;S Executive Chairman then provoked the management team to switch from this defensive position to making M&amp;S 'good'. The direction comes from the top. Plan A followed.</p> <p>Listen to your customers, but don't expect them to know what they want.</p> <p>The process is easier for manufacturing concerns with shorter supply chains, it is much easier to align them, especially when you are their sole or main customer.</p>		

Type: Non-participatory	Date: 15/03/2017	Reference: BC
<u>Brief Description:</u> <ul style="list-style-type: none"> <li>Goldsmiths College - Rethinking Capitalism – a Discussion</li> </ul>		
<u>Notes, Observations &amp; Insights</u> <p>Some organisations are led by a mission, this will lead to different innovation outcomes from one that is guided by the market.</p> <p><i>"Who gets the benefits from innovation? Are they reinvested in the innovators? If not, the industry will fail."</i></p> <p><i>"You must consider both the supply and demand side solutions"</i></p> <p><i>"You generate a lot of innovation by imposing constraints"</i> Michael Jacobs</p>		

Type: Non-participatory	Date: 03/10/2017	Reference: BD/BE
<p><u>Brief Description:</u></p> <ul style="list-style-type: none"> <li>• Prof Roger Levitt (Stanford) Bartlett CPM, Rethinking Infrastructure</li> <li>• Prof Roger Levitt (Stanford) Imperial College, Swimming Across Lanes: Addressing Barriers to System-Level Innovation in the Construction Industry</li> </ul>		
<p><u>Notes, Observations &amp; Insights</u></p> <p>Modular offsite production factories require investment – but in a downturn, they are stranded assets. The cost of stranded assets outweighs the transaction costs. This lesson will be re-learned in the next downturn.</p> <p>Construction organisations tend to go asset light and rely on hourly rated, flexible, but under-skilled human capital and specialist subcontractors. Construction is the ultimate gig economy. But these specialist organisations are unable to service long-term debt due to the uncertain cash flows, reducing their ability to fund innovation.</p> <p>Systemic innovation is difficult in mature industries such as construction. Any mature industry ends up with fragmented supply chains. This leads to the problem of broken agency. Technologies that break craft boundaries created by this fragmentation face challenges. Broken agency is fixed by vertical integration.</p> <p>Fragmentation occurs in three dimensions: vertical, horizontal, and longitudinal fragmentation (Fergusson, 1993). Lock-in arises through the imposition or evolution of institutional standards.</p> <p>Changing multiple systems at once with a weak system integration processes leads to problems. Cars &amp; planes are tightly coordinated, the processes have strong integration. Construction is a loosely coordinated industry, after Slaughter. Stinchcombe (1959) highlights that construction has a heavy reliance on craft administration of the production process. This hasn't changed much since. Electricians, architect, engineers spend hours training, much more than would a factory assembly line – hence craft.</p> <p><i>“If you expect a lot of change you want to have a flexible procurement route.”</i></p>		

## Appendix C – Memo-writing: Diagrammatic Memo Evolution

### Cognitive Structuring of the Construction Projects

Rich picture diagrams and cognitive mapping are techniques used to structure, analyse and make sense of complex problems (Ackermann, Eden and Cropper, 1992; Barrett and Sutrisna, 2009). The images produced are a reflection of an individual's personal constructs (Kelly, 2003, Appendix D) and how they have made sense of a situation (Weick, 1995). The cognitive maps resulting from this process of sense-making can exist as mental constructs, or can be externalised in any number of media. Such maps and pictures can be used to explore proposed interventions by presenting a working description of the subject of study, such as decision-making on construction projects (Edkins, 1997), without a need to implement the intervention on live projects. They allow researchers to articulate and present ideas, and to provide a focus for discussion to test actors' perception of the problem. Cognitive maps should include the steps necessary to reach a decision's end point.

Chapter 7 describes how the detail required for a task-level model of the construction project typically precludes an analysis of the whole project. Producing a description of the cognitive map of the interdependent, context-dependent, and emergent construction project is, therefore, challenging. However, such models are deemed to be useful as they can be used to explore interventions in a working description of the subject of study.

This Appendix presents and describes the key evolutionary points in the development of the cognitive map developed during the research project, proto-theories, exploring and describing the processes through which material specification decisions are taken. The proto-theories reflect the author's attempts to make sense of the problem of NMS specification, in the process of abduction ("*..the process of theorising what the world must be like for the effects observed to be as they are and not otherwise..*" Winch, 2018). In particular, the Material Adoption Model (proto-theory 6, Appendix C) presents an early mapping of the NMS adoption decision. Such maps allowed the research to conceptualise and articulate ideas to industry actors, comparing and testing actors' perception of the problem against the maps.

## Proto-theory 1

### Using unconventional materials in the built environment

An hypothesis

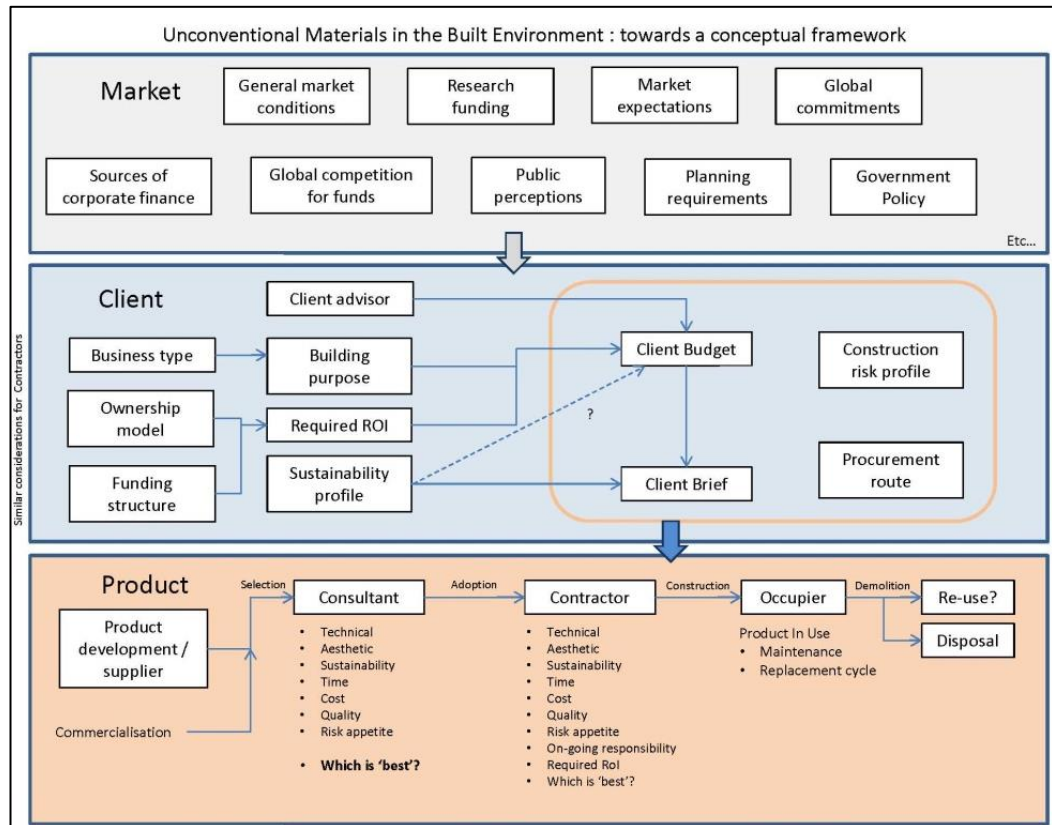
$$P_{adoption} = f(\text{Material Readiness}, \text{Client requirements}, \text{Procurement Route}, \text{Designer selection}, \text{Contractor Adoption})$$

This hypothesis represented the establishing idea behind the research. It was clear from early explorations that the problem of NMS adoption on construction projects was a multifaceted one that must be considered from multiple perspectives: the material, the client, the consultant and the project. It was also evident that the relationship between the material and the requirements of the client would be critical. The initial concept was to explore dependencies and correlations between these factors. The role of the procurement route was also noted, as this decision allocates the risk between the parties differently depending on which route was to be taken.

While helpful in beginning to identify the influences on the specification decision, the proto-theory is silent on time and emergence and on reflection, overly deterministic, providing no space for individual agency. The deterministic approach suggests that there is some combination of the identified factors that can ensure NMS adoption. This was clearly a naïve position.



## Proto-theory 2 (PT2)

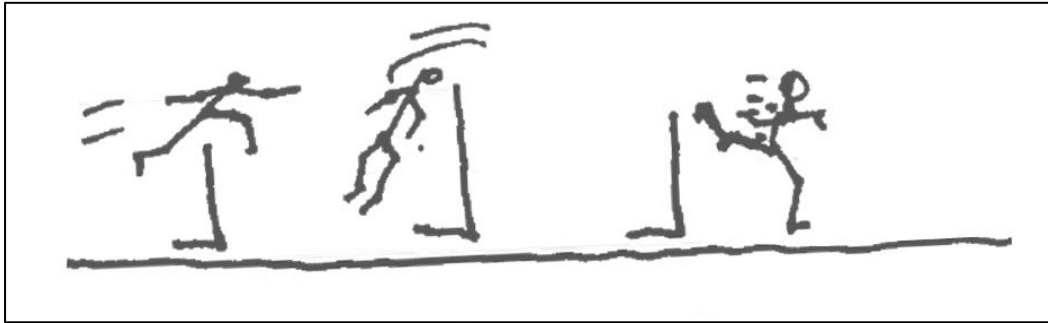


This hierarchical view of the problem begins to capture some of the complexity of the problem of NMS adoption, capturing an increasingly large number of influences on the decision to adopt an NMS. Over the course of the research, the list would expand dramatically (Figure 56, below, expands this list). Accommodating and accounting for all of the potential variables and influences on decision-making become unmanageable, highlighting the need for a contingency approach to exploring the problem of NMS adoption.

PT2 also highlights the role of the market in forming performance objectives at the client level, drawing parallels with the Multi-level perspective on technology transitions (Section 7.11), and the project hierarchy (Section 8.3.3). Unfortunately, PT2 then confuses the picture by introducing the product as hierarchical category. There was clearly some uncertainty about the appropriate unit of analysis at this early stage. Time is also introduced as a factor under the 'product' category, but only in the context of a generic delivery process.

Of note is the inclusion of market expectations in the highest level of the hierarchy. Expectations of outcomes guide both behaviour and decision-making.

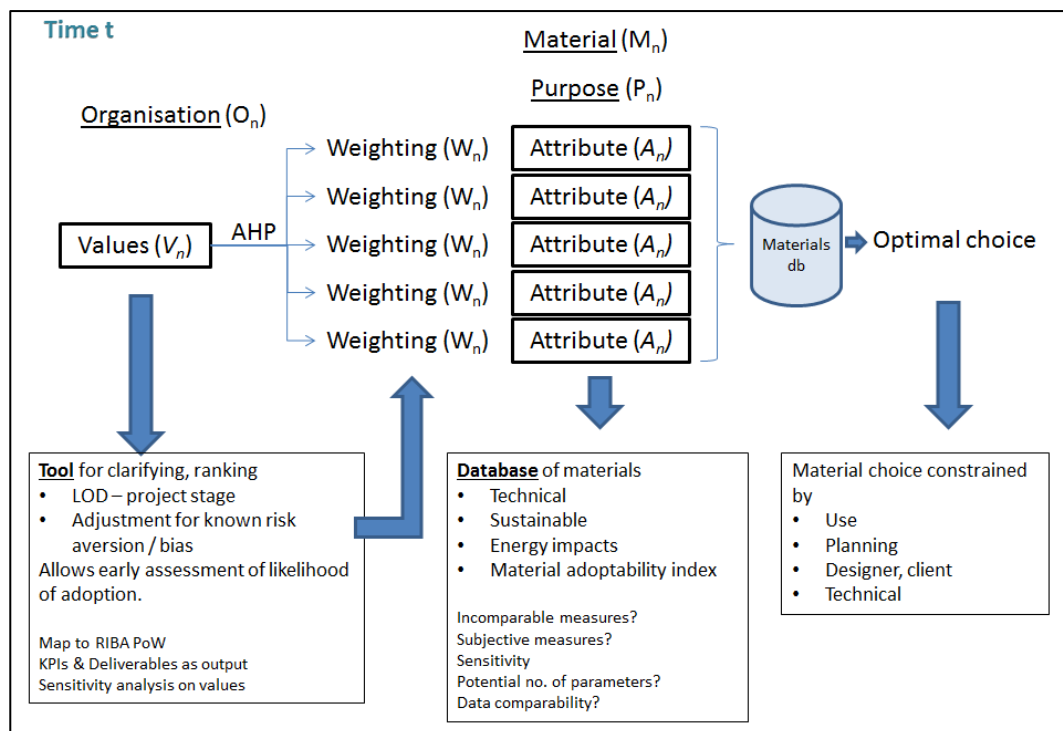
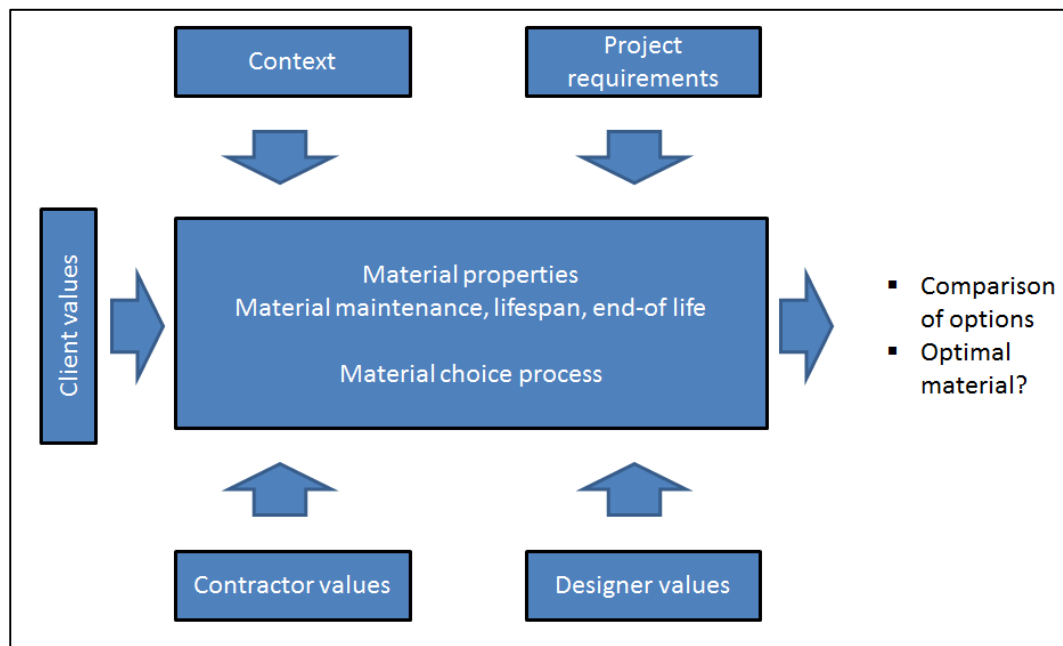
### Proto-theory 3 (PT3)



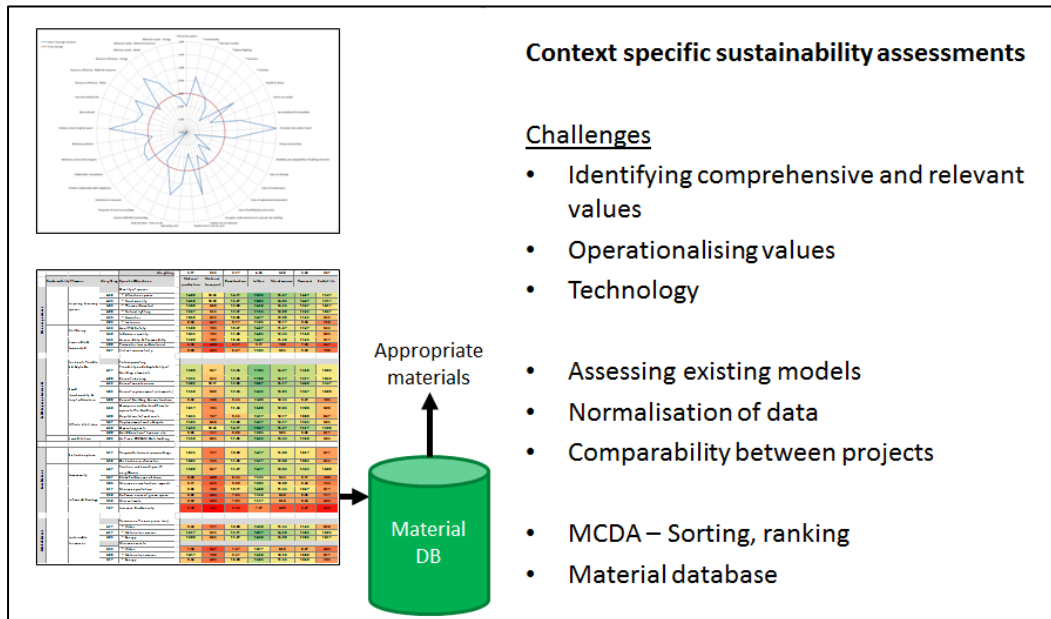
Early explorations of the problem of NMS implementation on projects identified the body of work relating to barriers to adoption. Extending the exploration of these barriers was briefly considered as an approach for the thesis. However, exploring barriers is considered problematic for addressing the problem of NMS adoption on projects (Section 9.5.3.2 refers). When viewed from a critical realist perspective, it became clear that the articulation of barriers by interviewees represents a subjective view of the problem of implementation, and may not identify the underlying cause. Further, to ensure implementation, all of the articulated barriers must be addressed. As the image suggests, even after clearing a first identified barrier to implementation, another subsequent barrier may manifest. A repeated game of barrier 'whack-a-mole' would be needed to ensure successful implementation. It was unclear which barriers researchers and practitioners should be targeting. This insight suggested that the systemic causes of the barriers should be considered as a research area, rather than the barriers themselves.

### Proto-theory 4 – Approach to Addressing the Problem (PT4)

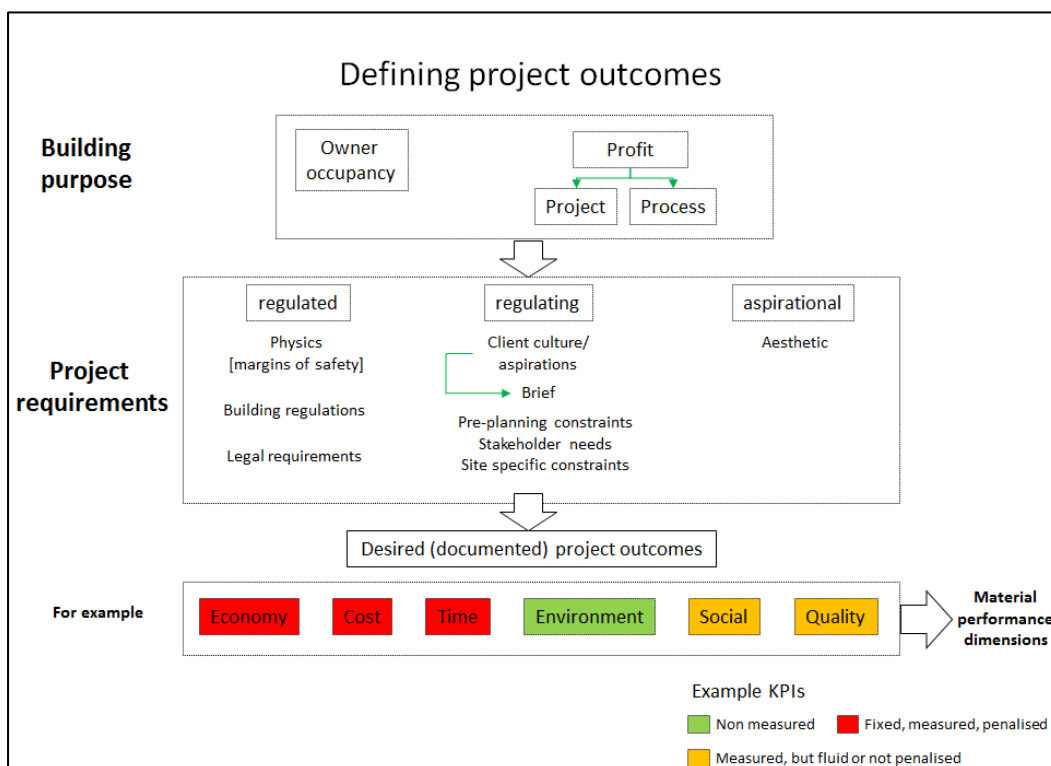
The possibility of developing some form of decision support tool was considered to address the problem. The conception behind this exploration is that there is a 'best' material for each job, finding it would address any barriers. This seemed like a deliverable solution, and led to an initial model being developed and deployed in participatory event D (Appendix B). The images below represent the explorations of this approach to material selection. However, as described in Chapters 5 and 6 and data point D, the problem of material selection is multifaceted, with technical, financial, and personal concerns influencing the decision. The GRI G4 reporting framework was considered as a structured means of comparing actor views on the attributes that should be considered. However, there was limited information material performance data available to deal with all of these attributes required of the decision for a given construction solution. Further, eliciting preferences and identifying a globally acceptable ranking took a long time. The exploration of the theoretical challenges presented by such a tool led to the incorporation of the notion of values & value into the abductive process.



A similar approach had been developed by Watson (2015) in relation to non-conventional, low impact, construction materials, but its use was limited to engineers who may not have full alignment with the client and their stakeholders (e.g. participatory observation event D). It was during this phase of the project it became clear that while the project sponsors and researchers believe that reducing embodied impacts was important, the client may not. The search therefore should not necessarily be for a particular NMS, but an NMS that was appropriate to client needs and demand. A contingent, demand responsive approach to specification, was needed rather than one driven by the features of the technology.

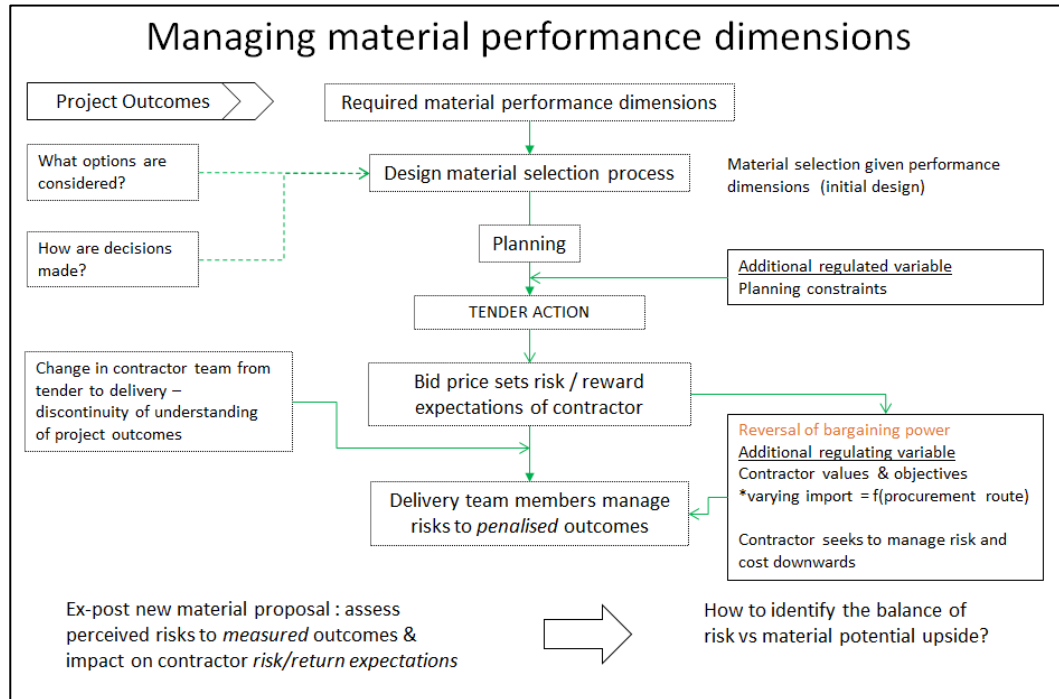


## Proto-theory 5 (PT5)



This cognitive map incorporates the notion of regulated, regulating and aspirational criteria for the project (modified to performance requirements, expectations and aspirations discussed in Section 8.3.2.2). The map remains unclear in terms of its unit of analysis and is, therefore, limited. The map does, however, begin to incorporate the notion of project outcomes, but assumes that there is a unified project-wide perspective of outcomes and requirements. Attempts were also made to provide a more granular

view of the types of projects and clients to see whether this influenced the implementation decision. Observations suggested, however, that implementation was unlikely to be strongly correlated to client and project type – examples of both pathological and extreme cases (Section 3.8) were found for comparable building and client types.



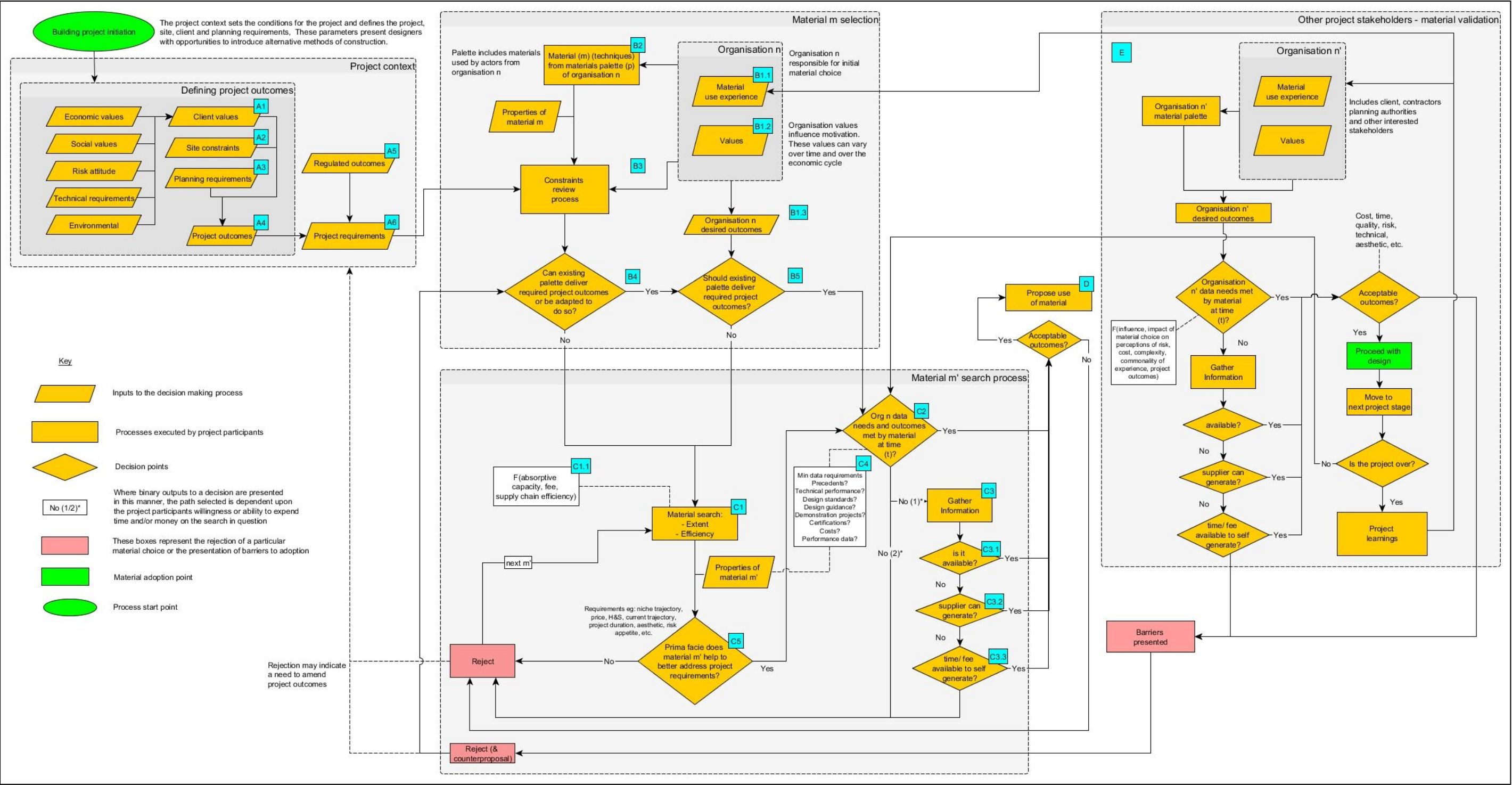
Time is again considered in PT 5 through the project development process through an event sequence review, expanding the complexity of the problem. However, the degree of abstraction adopted here remained too high, and it is unclear how contingencies could be resolved. The notions of sanctions are also introduced in PT5 along with a vague notion of 'risk', which was subsequently clarified as lack of outcome certainty.

### Proto-theory 6 - The Material Adoption Model

This was a first attempt at a detailed mapping of the NMS implementation decision process, combining observations and the literature (in particular Rogers 1995). The mapping begins to address some of the contingencies observed during the research. However, it fails to engage with the emergent nature of some of the project requirements, and fails to allow a thorough exploration of project hierarchies, despite the distinct recognition of most of the levels of the hierarchy described in Chapter 8, save for the individual. The mapping is described in detail in Jones (2014). Many of the concepts articulated here are present in the assessment framework discussed in Chapter 9. This decision mapping was reviewed and approved by industry stakeholders and academics.



Proto-theory 6 (PT6) The Material Adoption Model





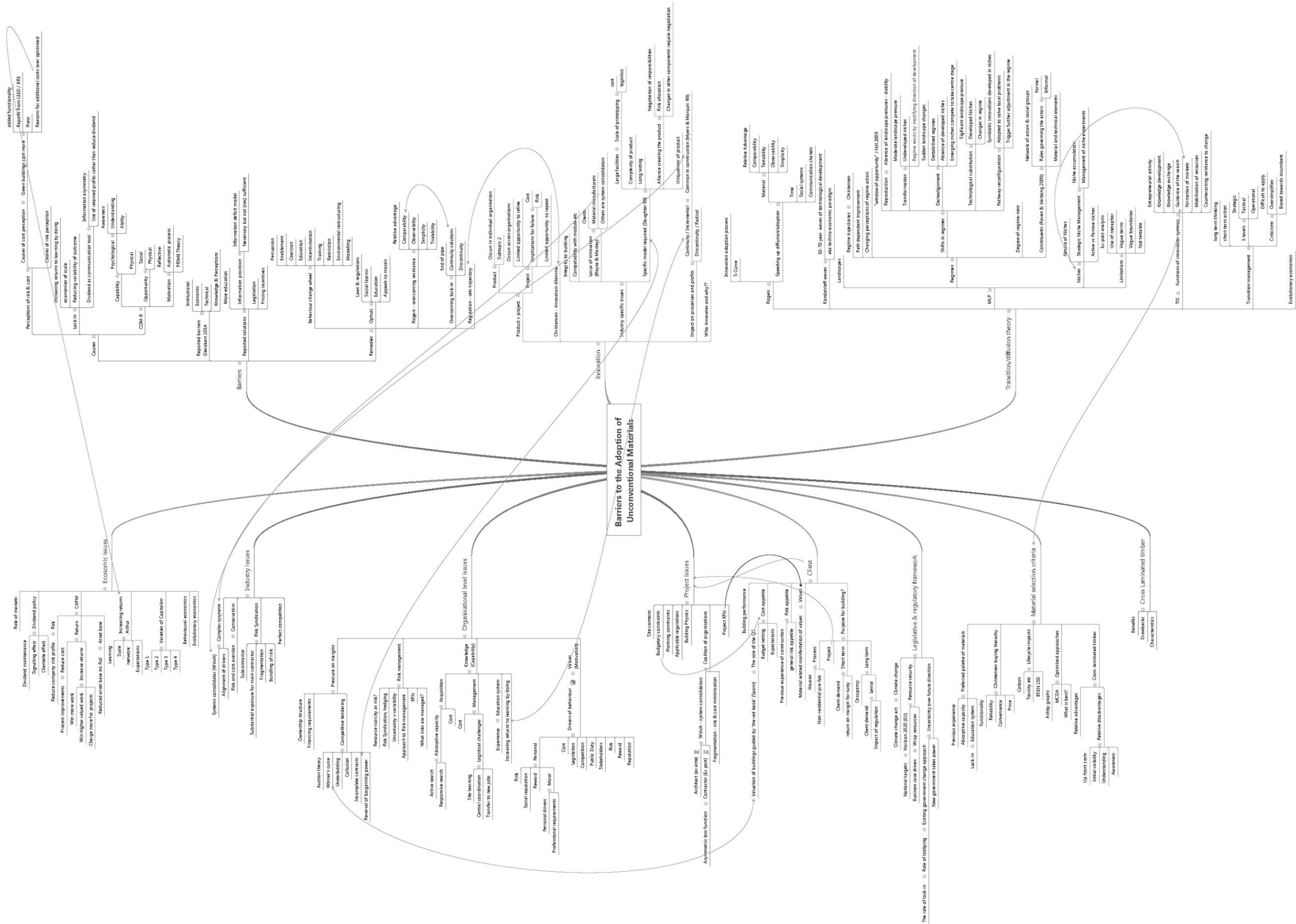
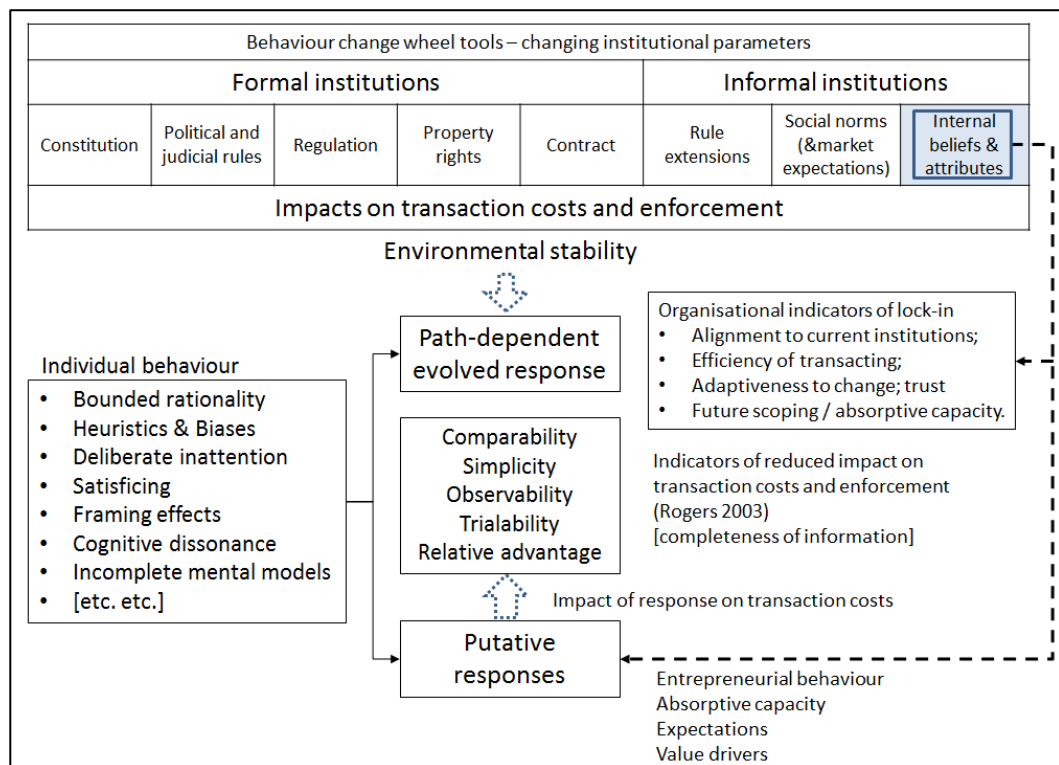


Figure 56 – Concepts and Bodies of Literature Explored During Phase 1 of the Project.



## Proto-Theory 7 – Attempts to Integrate Institutional Economics

It became apparent that the implementation of NMS on projects was both contingent and dependent upon the flawed decision-making of individuals. Further bodies of literature were reviewed to explore this socio/techno/economic problem. PT 7 was a first attempt to integrate all of these bodies of literature, including behaviour change, institutional economics, and transaction costs economics. PT 7 shows how formal and informal institutions inform both the need to specify and NMS and the desire to specify.



$$E(\text{Value}) > E(\text{Transaction Costs})$$

Where

$$E(V) = f(E(\text{drivers of value}, \downarrow \text{long/short term risk}), \text{discount factors})$$

$$E(\text{TC}) = \sum E(\text{market, transaction, information, measurement, enforcement costs})$$

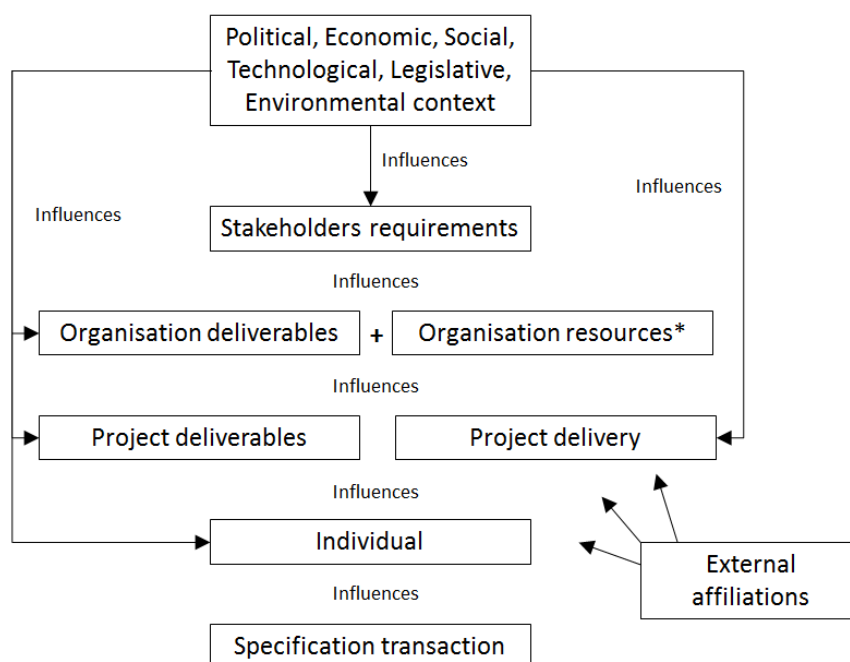
This led to the development of the hypothesis above that describes the cost benefit analysis explored further in Appendix A, and highlighting the role that the characteristics

of the material have on the expectation of transaction costs. As such, this hypothesis focused on the specification transaction, as opposed to the specification decision. Accordingly, the implementation on project duration (or other impacts) was ignored.

At this time the clear distinction of perceptions in value between the context, client, project, and PBOs become more evident, leading to a more thorough review of the 'PBO problem'. PT 7 also begins to distinguish more clearly between the structuring of the decision context and the specification decision itself.

### Proto-Theory 8

Developed in November 2016, PT8 establishes the hierarchical series of influences on the specification transaction. The role of external affiliations – such as professional bodies – is also made explicit here. While this has been removed for clarity in the description presented in Chapter 8, the influence of the external affiliations is represented in a DMU's value drivers.



\* Resources include intellectual and physical capabilities, processes and systems, absorptive and adaptive capacities

At this stage, the emergent nature of the requirements and actor expectations was identified. This challenges any deterministic model of the construction project and requires consideration of both the specification decision and the context in which it is made.

Commercial organisations are motivated by positive profits (continued existence) → *Hypothesis*

Adoption will occur when

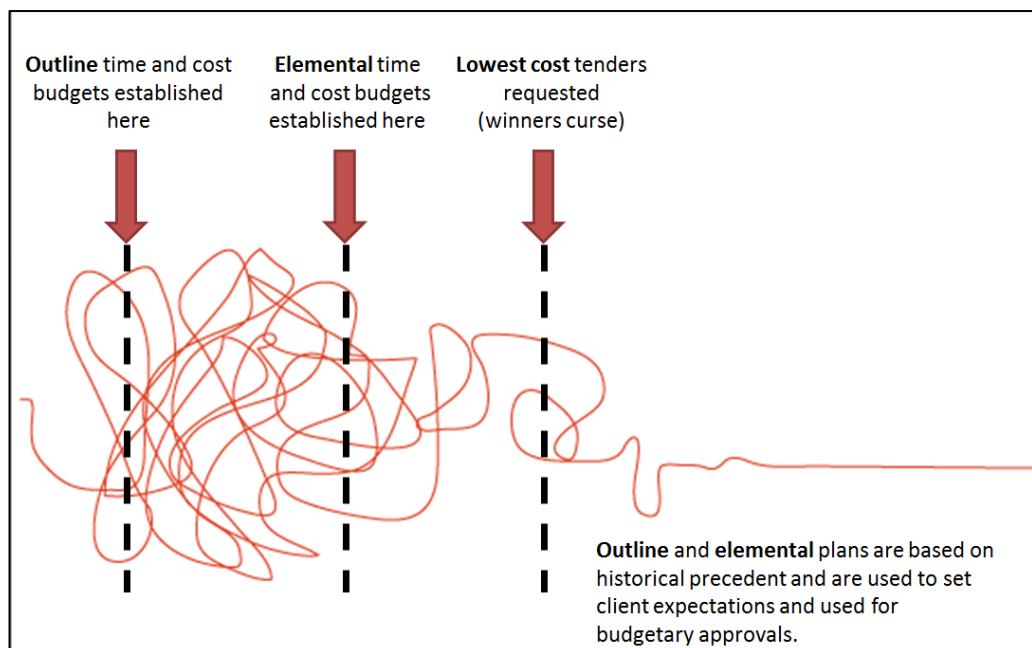
Expected value > expected costs

The question then turns to the nature of both expected cost and value.

BUT...

... expectations are a function of project stage (time)

... so the decision is dynamic



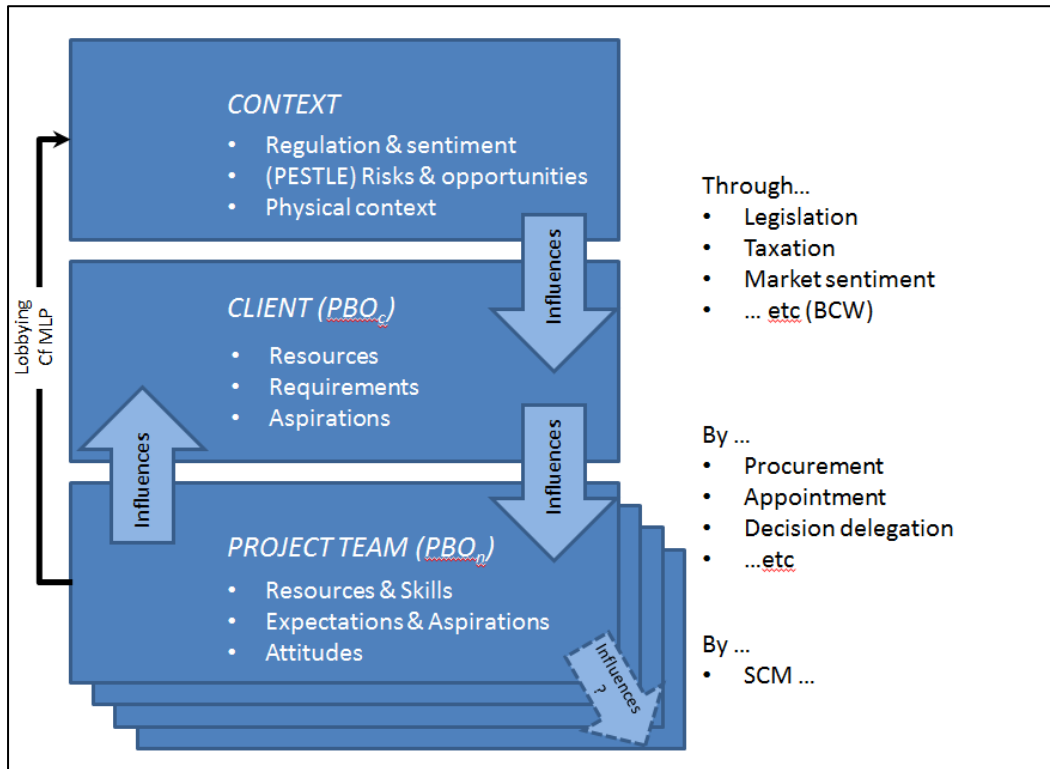
Adapted with permission from Jacobito Design

<https://santafe-nm-webdesign.com/design-process/web-design-process-part-one-project-comprehension/>

Exploring the emergence of architectural design highlighted the uncertainty accompanying the process, and how early key expectations on time and cost are established. Certainty, however, is only possible with completion and the reduction of abstraction. Decisions made at these early junctures, therefore, must be made with the use of assumptions. These assumptions determine much of what follows.

## Proto-theory 9

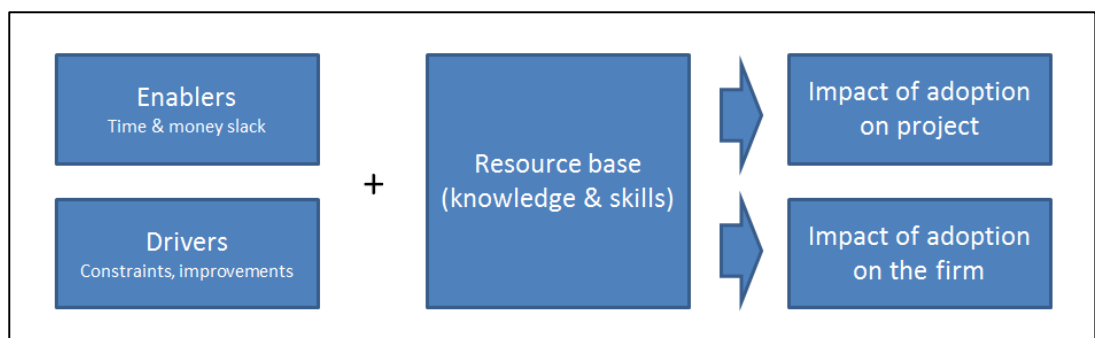
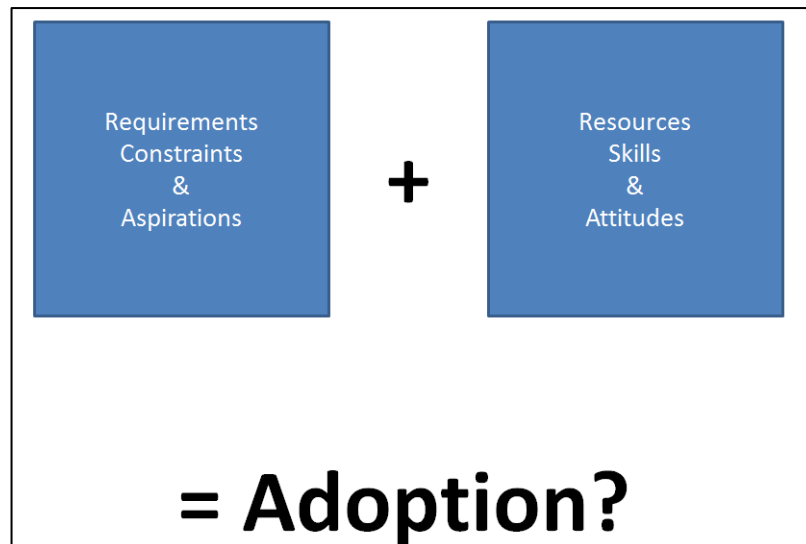
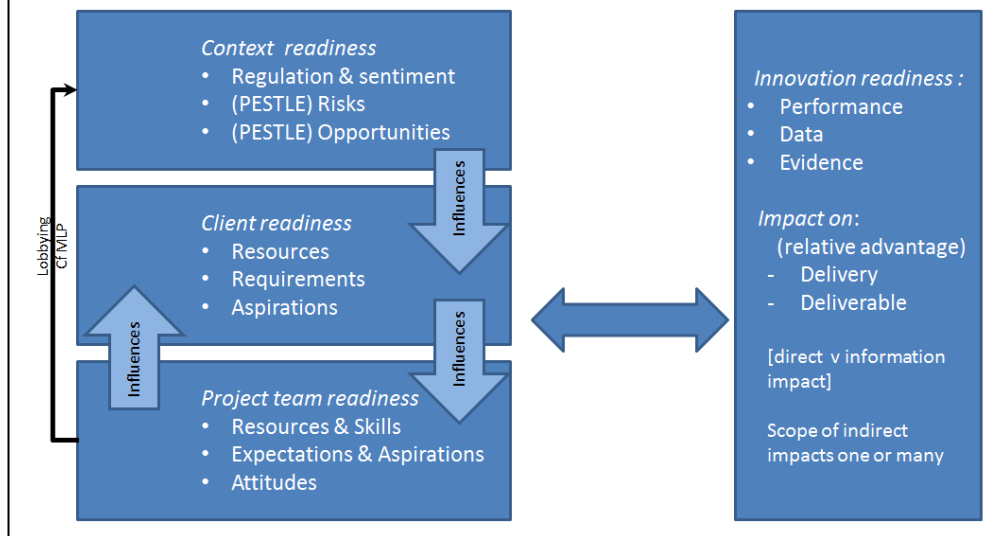
There is a formalising of the hierarchical nature of decision-making on projects reflected in Figure 22. However, in this explanatory image, the specification decision is absent, and the role of the individual conflated with the PBOs. The influence of multiple PBOs is considered, but this simplistic presentation ignores the role of time and emergent conditions.



Further, PT9 made explicit the need to consider both the technological readiness of the NMS being specified, and the readiness of the project to accept the NMS. That is, the project team must have the endowments necessary to address any technology readiness deficits. Note that there is no separate exploration of the resources committed to the project, the client is used as a surrogate for project at this time. PT 9 also re-introduced the COM-B model to the analysis (previously included along with PT 6) to describe how capability and motivation align with the project factors identified in the hierarchy. These were termed drivers (motivation) and enablers (capability) and presented in Jones et al., (2017) (included as Appendix H). The distinct impacts of implementation on project and PBO are also highlighted here

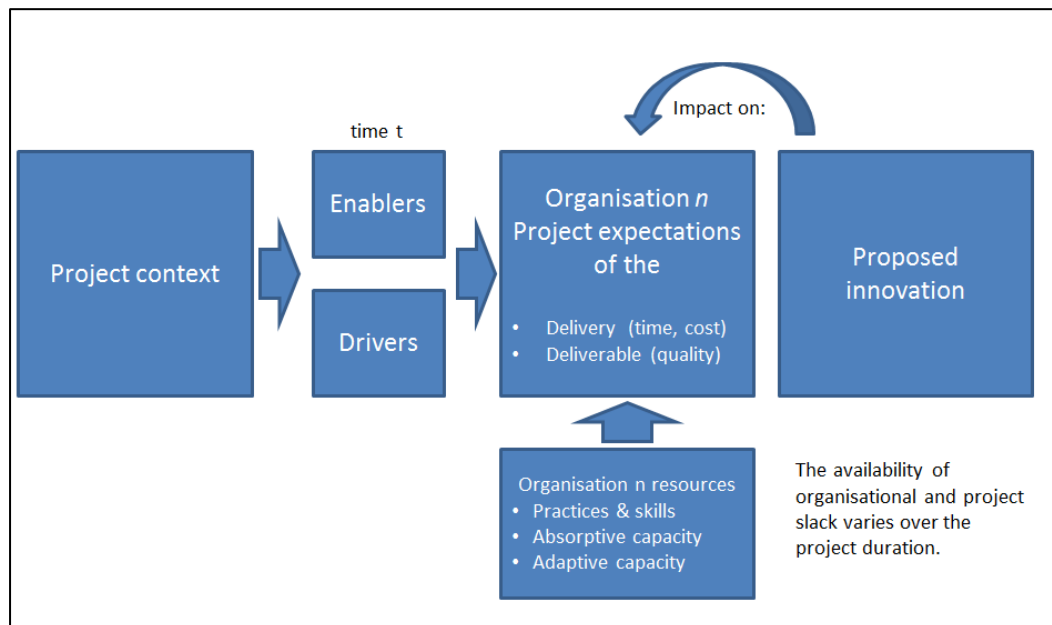
However, PT 9 ignores the impact of time and emergence.

## Readiness to adopt?



## Proto-theory 10

PT10 extends PT 9 by re-introducing the idea of expectations to the analysis.

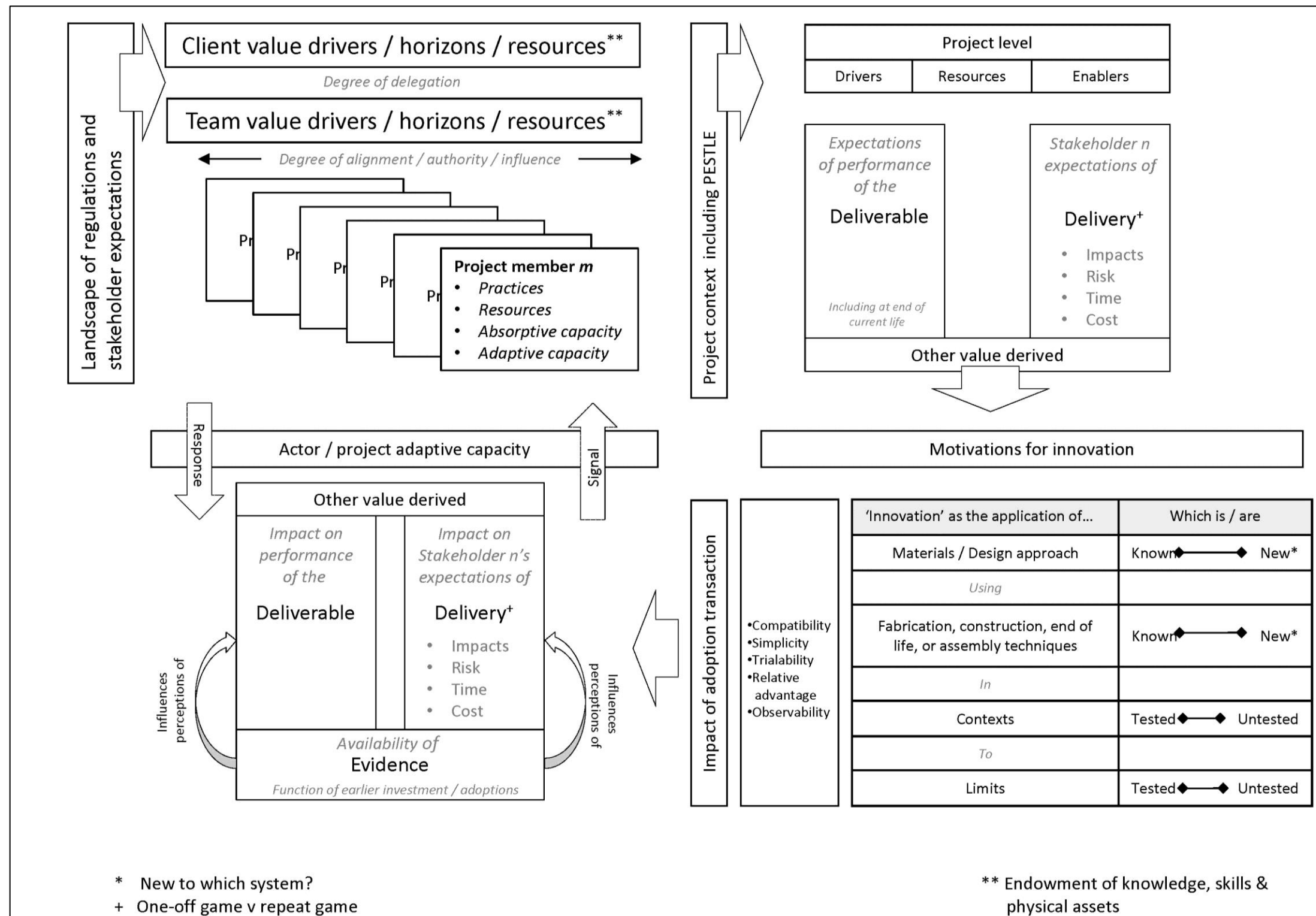


Where expected outcomes have been defined at the point of decision, the impact of the implantation on those expectations will frame the PBO (or DMU's) response to the proposal to specify an NMS.

## Proto-theory 11

PT11 represents an attempt to integrate all of the insights gathered on the project. Including:

- The distinction project actors and the project hierarchy.
- The impact of decision/authority delegation.
- The need for alignment of actor motivations.
- The influence of various project actors' conceptions of value.
- The capability, motivations and expectations of actors.
- The role of the context.
- The impact on the delivery of the project and the end product and associated conceptions of value.
- The impact of implementation on expectations.
- Technology readiness, and the 'adoptability' of technologies (after Rogers 1995).



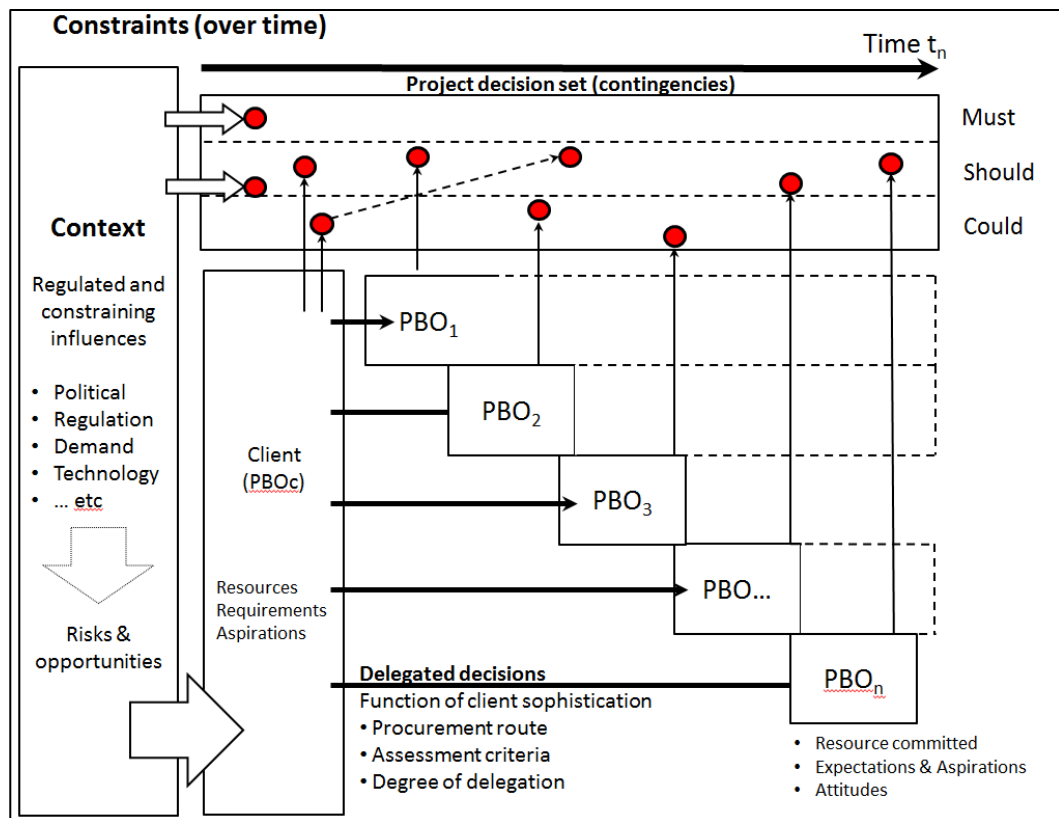
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However, PT 11 was unable to account for the influence of time and emergence, nor the distinct role of different project requirements (identified in PT5). Further, while PT11 identified the dynamics in the specification decision it provided no means by which the decision could be located in either the project or time. It attempts to do too much at once.

### Proto-theory 12

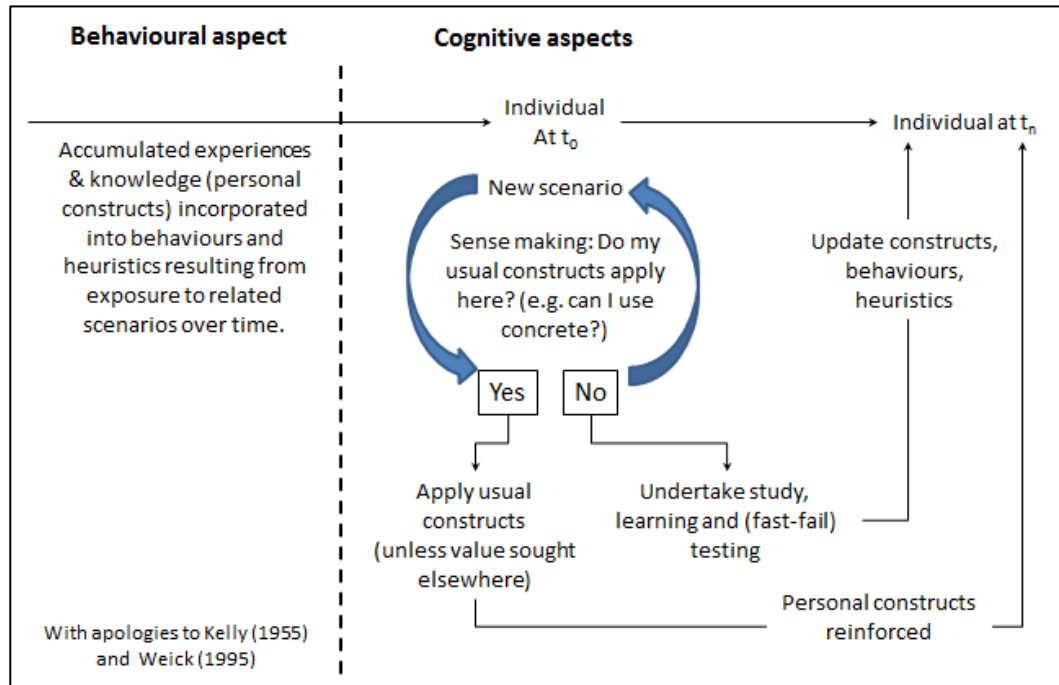
PT12 separates consideration of the specification decision from that of its location. As a result, a much clearer picture emerged. PT12 makes explicit the consideration of time, and the hierarchy of actors in the project, identifying their distinct resources, requirements and aspirations (later modified to requirements, expectations and aspirations). This separation forms the basis of the model presented in Chapters 2, 7 and 8 of this thesis.





## Appendix D – Schematic: Interpretation of Human Sense-making

While significantly beyond the scope of this thesis, this Appendix has been produced to capture the author's understanding and interpretation of the psychological aspects of decision-making as they apply to the thesis. The schematic below shows that...



*“...sense-making can be viewed as a recurring cycle comprised of a sequence of events occurring over time. The cycle begins as individuals form conscious and unconscious anticipations and assumptions, which serve as predictions about future events. Subsequently, individuals experience events that may be discrepant from predictions. Discrepant events, or surprises, trigger a need for explanation ... and correspondingly, for a process through which interpretations of discrepancies are developed.”*

(Louis, 1980)

From birth, individuals are constantly faced with new situations. The development process is a sequence of attempts to understand these new situations, to allow the individual to respond accordingly, fight or flight being the most basic of responses. Stimulus: response; a wasp appears, I flail my arms around. As they age, humans begin to identify and learn about patterns and norms in the world and assign meaning to these patterns creating rules of thumb (heuristics) and personal constructs of reality that are developed and shared, social practices and norms emerge. The accumulation of heuristics allows individuals to operate, and together they determine their behavioural, reflexive, response to situations. With new information, these behaviours can change.

When faced with an unfamiliar situation, the individual may attempt to apply their behavioural responses to the new situation, but they may not be appropriate. In this circumstance, cognitive processes must be initiated to assess, understand and respond to this new stimulus (motivated reasoning, Fellows and Liu, 2018). Morphogenetic change of personal constructs follows from a period of reflection or experimentation, updating them to reflect the new circumstance. This echoes the processes identified by Darwin and Schumpeter.

The process of placing stimuli into frameworks is most visible when predictions break down, suggesting that surprise, and sense-making are related to expectations (Weick, 1995). It is clear that both the research project and the design and delivery of the construction project are both forms of sense-making. At the level of the project, actors review the constraints in front of them for a given project and consider whether their existing knowledge, experience, rules of thumb etc., can accommodate the situation in front of them.

If existing knowledge, experience etc., cannot accommodate the situation, then the individual must try to make sense of what is in front of them to address the design requirements. The search and selection process begins.

## Appendix E – Technology Readiness Levels

Recognising that new technologies have varying degrees of maturity, NASA introduced the concept of Technology Readiness Level (TRL) to describe and delineate nine distinct stages of maturity (Mankins, 2009). The readiness levels run from TRL1 (basic principles observed and reported, i.e. fundamental research) through to TRL9 under which a technology has been previously proven through use in the proposed use context (Figure 57). As a technology's TRL increases, the information deficit and uncertainty over performances reduce. As a corollary, the additional cost and time required to move to TRL9, when the product is considered suitable for use, also falls. TRLs have been adopted by UK Research Councils, and adapted for use in major construction projects (see, for example, Crossrail, 2013). While TRLs were not seen to be particularly prominent in practice during the research, the concept can provide an indication of the likely scale of time and costs impacts of a taking a proposed NMS to a TRL level at which it might be used in a construction project. An interesting piece of future research might be to establish whether there is any correlation between knowledge of an NMS and the gaps between actual and perceived TRL in construction materials, influencing the expectations of future time and cost investment. This would build on the work of Qian, Chan and Khalid (2015) who explore the transaction costs of 'green building' in a Hong Kong context.

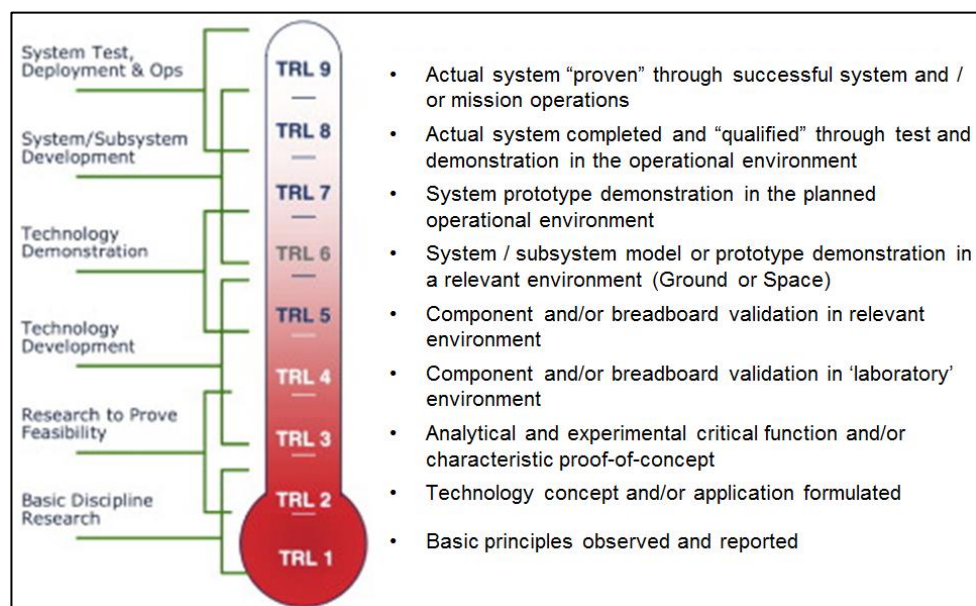


Figure 57 – Technology Readiness Levels (TRL) for space technologies  
Reprinted with Permission from Mankins (2009)

Buildings are usually designed for longevity, and the impacts of failure can be catastrophic to both life and the financial standing of project participants. Accordingly, "*failure is inadmissible*" (Rabeneck, 2007). Accordingly, it is rare to observe an NMS with a TRL below six or seven being proposed for critical elements of construction projects (e.g. structure, façade, services). Performances generally need to be proven, evidenced,

ideally certified and typically warranted by the supplier, or architect, to facilitate specification and implementation (“*Your client is expecting a warranty, that’s what a lot of it comes down to[...] someone has got to have the confidence to sign a document to support it*”, data point 9). It is interesting to observe during the research that novel, uncertified solutions are more common (indeed, celebrated) in less permanent elements of a building (‘stuff’ in the 6-s model described in Brand, 1997, Interview VII). Even those organisations that are keen to innovate and propose low embodied GHG materials were unwilling to wholeheartedly support NMS that are not yet proven and commercialised into critical applications:

*“Is it an experimental thing? Is it commercial? If it’s not commercialised yet, then there’s [safe] places where it might be best to trial it”*

*Interview 7*

In evidence to the Lords’ Select Committee on off-site manufacture for construction, Tim Carey, Chair of Wilmott Dixon’s national off-site innovation group described the need for confirmatory evidence:

*“...effectively we are asking a customer or an end user to make a different decision — to elect to support the use of [an innovative approach] rather than something that they know, and may think is a better option. [...] if we are asking someone to make an informed decision, they need to be informed. We [need to be able to] prove that where we use off-site, we have the benefits ...”*

*House of Lords Select Committee on Science and Technology, 2018*

The point was put more succinctly in Interview 7, “*...there’s a big risk there, [...] you need to provide more evidence...*”.

## **Appendix F – A Copy of Jones et al. (2016)**

This article can be found at Construction & Building Materials by following the link below.

<https://www.sciencedirect.com/science/article/pii/S0950061816313514>





## **Appendix G – A Copy of Jones (2017)**

## **Effecting change in construction: the construction project as decision set**

It is recognised that change is needed in the construction industry to achieve sustainable development (HMG, 2013b). The industry is known to be conservative and risk-averse, this is largely because innovation in construction is typically considered on a project by project basis. This limits opportunities for project teams to overcome material lock-in (Nelson and Winter, 1982; David, 1985; Arthur, 1989; Unruh, 2000; Foxon, 2007) by specifying unconventional material solutions (UMS) which can reduce the impacts of the construction project.

Research exploring how to overcome this material lock-in typically adopts a normative position on the adoption of UMS. This leads researchers to explore the specific barriers to the adoption of UMS (Gieseke et al., 2014 provide a meta-study). Such studies present and categorise the reported barriers. Researchers then propose solutions to overcome the identified barriers to adoption, such as:

- The use of laws, regulations or incentives;
- Programmes of education;
- The provision of information to the decision-maker;
- Expanding the (value) attributes, time horizon or stakeholder base to be taken into account in the decision-making process;
- Coinciding the decision-making processes of the system integrators (IPD);
- Integration / stimulation of the supply chain;
- Behaviour change initiatives.

These interventions attempt to address lock-in, bounded rationality (North, 1990; Simon, 1991; Gavetti, Levinthal and Ocasio, 2007) and human biases in decision-making (Kahneman and Tversky, 1979). They do so by influencing the 'non-linear, unsystematic and reactive' (Soetanto, Glass, et al., 2007) decision-making in construction. However, these interventions do not account for the highly contingent nature of the construction project. Further, these proposed interventions in decision-making are not located in the context of a theory of construction. As such, it is hard to determine whether the analyses and interventions are sufficient to encourage the adoption of UMS.

Literature searches for "theory of the construction project" and "construction project theory" highlight studies focusing on project and economic management and project governance. These models focus on control and delivery of the project. Delivering these outcomes conflicts with the desire to deliver innovations such as UMS on a construction project (Murphy, Perera and Heaney, 2015). Accordingly, the aim of this paper is to present a model of the construction project in which to locate existing and future research aimed at encouraging the adoption of UMS.

## ***Research Method***

Data and insight have been gathered through literature & case review, action research, interviews and reviews of secondary data. These data have been analysed using both inductive and abductive inference to arrive at a middle-range descriptive model (Merton, 1968) of the construction project as decision set. A critical realist position has been adopted.

### ***Model of the construction project as decision set.***

Decision-making involves arriving at a solution (output) through the consideration of (input) variables relevant to a decision. For a given decision, these input variables might be constrained. If not, the decision is considered to be unconstrained. The outputs from each decisions may become constraining on later decisions, limiting the potential outcomes from those subsequent decisions (Archer, 1969). Adopting this view, it is possible to reframe the entire construction project as a multi-level hierarchy of decisions (agency) accounting for constraining variables (structure).

#### ***A hierarchy of constraining variables***

Each decision in a construction project could take into account a potentially limitless number of variables. However, even before the project is conceived, constraints are imposed by the political, economic, social, technological, legal and environmental (PESTLE) context of development (Boyd and Chinyio, 2006). Such constraints are termed here *context variables*. These context variables reflect the societal concerns embedded in laws, regulations, planning requirements and the physical limitations imposed by the site to be developed. Context variables will have a constraining influence on the decisions that can be made on the project by a developer client on a given site. Even with these constraints, there remain a vast number of decisions to be made to bring the project to completion.

The project client will have value drivers - needs and wants - that they would like reflected in their project (Spencer and Winch, 2002). The nature of these drivers will vary from project to project, and can be extended by the consideration of requirements a wider group of stakeholders (Storvang and Clarke, 2014). These value drivers, termed here *client variables*, act as further constraints on decisions to be taken during the project.

While the client will be competent to make suitable decisions in some circumstances, many will fall outside of their competency (Reve and Levitt, 1984; Winch, 1989). Exploration of the options available to the client for each decision is, therefore, typically

delegated to specialist project-based organisations<sup>13</sup> (PBOs). The exploration of the decision space by the relevant specialist will be constrained by both context and client variables.

PBOs then present their view of options for each decision, one of which will be adopted by the client – either as binding or advisory on later decisions. However, these PBOs are not unbiased in their decision-making. They incorporate variables into the decision-making process which, while not considered as context or client variables, are valued by or constrain the PBO in question (Bell, 1994; Male et al., 2007). These *PBO variables* will influence the recommendations made to the client.

After incorporating context, client and PBO variables into the decision-making, there remain a vast number of unconsidered variables for each project decision. The process of lock-in and the institutionalisation of processes precludes consideration of these *unconsidered variables*. The attempts to influence decision-making described in the introduction aim to move decision variables from the set of unconsidered variables to one of the other three categories. These four variable types are presented here as a hierarchy (Figure 1).

The relative success of proposals in overcoming material lock-in is dependent upon the extent to, and manner in which the decision variable being targeted is constrained by higher level constraining variables.

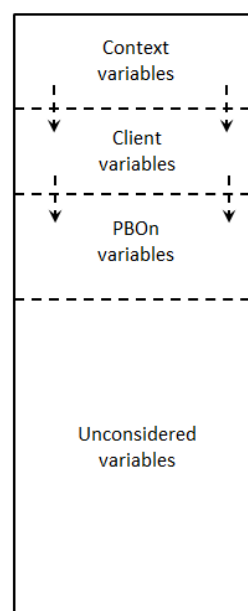


Figure 58 – Hierarchy of decision variables

*The dynamic nature of structure and agency in decision-making in construction*

<sup>13</sup> The client is also considered to be a PBO, and subject to similar pressures.

The decision constraints imposed by the different tiers of the hierarchy of decision variables have been presented so far without any consideration of the timing of the constraining decision. It is clear though, that the dynamic nature of the project should be considered as it has a significant influence on the agency of project actors.

Before a project has been decided upon the project is constrained only by certain context variables. All else is agency. At this early stage, unconstrained project actors are willing to explore new areas, to posit wild schemes and embrace innovations (Figure 2).

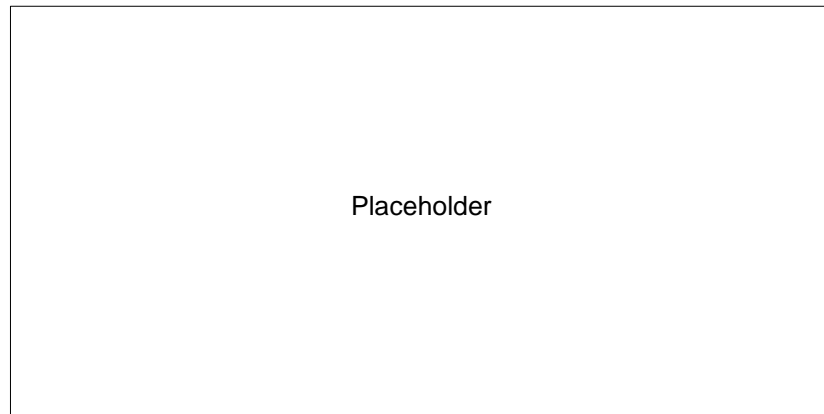


Figure 59 – Unconstrained Architecture: Archigram's Urbanism  
(removed from this thesis)

#### *Decisions at the project level*

When presenting interventions to encourage specification of UMS, it is critical to understand what is already constrained, or constraining. Unconventional approaches to construction typically carry a time / cost premium. Where finances or time have already been constrained, it is unlikely that the provision of information provision to design specifiers will overcome lock-in, unless that specification addresses a superior constraining variable.

The RIBA Plan of Work (RIBA, 2013) defines the anticipated order in which decisions on projects are made. While there is an increasing flexibility in the latest version of the Plan of Work, the earliest decisions at Stage 0 remain related to the 'business case' and programme for the project. This establishes constraints on costs and time of the project at the earliest opportunity<sup>14</sup>, at time when there is least certainty of the project. Concept design follows, eventually, at RIBA Stage 2.

#### *Decisions at the PBO level.*

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<sup>14</sup> It is interesting to note that in the earliest version of the RIBA plan of work design preceded the development of the budget plan.

In a similar manner, timing is also important when considering PBO variables. Before budgets are set for projects, or tenders submitted, organisations are unconstrained in how they might respond to a given project requirement. In deciding how much to bid for work, a PBO must review context and client variables and make assumptions as to how their work will be carried out to reflect their own value drivers. These assumptions are incorporated into bids and hence the PBO constraining variables. including the time and cost of the work they are to undertake.

### ***Implications***

This middle-range model provides a new conceptual framework for locating proposed interventions to encourage the specification of UMS. Further, this view of the construction project challenges PBOs to explore more fully the decision contexts into which they are specifying UMS. Such an exploration might lead to the identification of context or client variables limiting the delivery of client value which in turn could promote specification of UMS.

### ***Conclusion***

This paper has presented an outline of a model of the construction project as constrained decision set in which to locate existing and future research on the adoption of UMS. Dependent upon the UMS proposed, these constrained decisions can act as either initiator of, or barrier to innovation.

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## **Appendix H – A Copy of Jones et al. (2017)**



## Construction innovation: theory & practice

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### Abstract

The challenges of reducing global output of greenhouse gases and the need for resource efficiency require a step-change in the way we construct buildings. However, the construction industry has a reputation for being conservative and slow to change. This lecture will present a case study of innovation and describe an emergent framework for describing innovation in construction.

**Keywords:** Construction innovation; Case study; innovation framework; Ferrocement;

### 1 Introduction

A recent scenario analysis suggested that if the UK construction industry is to meet its greenhouse gas targets, embodied carbon intensity in construction projects may need to fall by up to 67% by 2027 (1). Innovation will be critical to reach this goal. However, the industry's reputation for conservatism suggests that the required change may not occur unprompted. Previous research has shown the importance of capability, opportunity and motivation for delivery of construction innovation on construction projects (2). These aspects are explored in the context of a case study. An emergent framework for assessing interventions to promote innovation will then be presented.

### 2 Innovation case study

The Stavros Niarchos Foundation Cultural Centre (SNFCC), Athens, Greece was opened in 2016 providing new homes for the Greek National Library and National Opera. While the project is a showcase of innovative engineering, the

innovation process for the 10,000m<sup>2</sup> ferrocement solar canopy is the focus of this presentation.

#### 2.1 Motivation – constraints & aspirations

##### 2.1.1 Project contexts, client requirements

The client wanted to deliver a world class cultural centre in Athens, a seismic zone. After an international competition, the Renzo Piano Building Workshop (RPBW) was appointed to deliver the project. The client adopted RPBW's design vision for the scheme. The strength of the client's commitment encouraged the team to work together to overcome the site constraints to deliver the scheme and architectural vision. That vision, in itself, became a constraining factor on project decisions, leading to the development of the ferrocement canopy.

##### 2.1.2 Aspirations: Delivery v deliverable

While the time and cost budgets during delivery were important on this project, the client also wanted to ensure that RPBW's vision was successfully delivered. To achieve this, they were

willing to accept the time and cost implications of some limited innovative activity. This aspiration provided a constraint which provided the opportunity to apply innovation to the project.

## 2.2 Capacity – resources, skills, attitudes

### 2.2.1 Addressing the Information deficit

The creative process, by its very nature, challenges what has gone before; new uncertainties require exploration and validation. When ferrocement emerged as a potentially/theoretically suitable solution for the canopy, evidence and performance information was sought. While some technical guidance and exemplar projects were available for ferrocement, the context and scale of use here was new – there was an information deficit.

Addressing this information deficit required a significant investment in time and money to undertake calculations, computer modelling, physical modelling, and prototyping ('learning before doing'). It is at this juncture that the importance of the client focus on deliverable over delivery became important. Had time and funding not been made available to address the information deficit, the canopy could not have been developed to its current form.

### 2.2.2 Skills and attitudes

Prior research has shown the importance of cooperation, commitment and leadership (3) to innovation adoption. These skills and attitudes were all demonstrated during the project. The whole team committed to the vision and worked well together with common purpose to create and deliver the design, demonstrating their own personal commitment to the scheme and innovation. Commitment from the client, project manager and contractors ensured that the innovation was given space to develop, and leadership from Expedition Engineering ensured that the canopy was taken through to completion. Collaboration across the project team was critical.

The delivery team also needed to develop the skills and equipment to deliver the pre-fabricated ferrocement panels. This required an investment of time and money to finance the 'learning by

doing' phase of the project which was enabled by the client's investment in innovation.

## 3 Conclusions

Innovation requires resources to address shortfalls in information and skills. In projects that are tightly coupled and for which delivery is constrained by time or finances, the resources available to make this investment may not be available. This case study supports the proposition that the adoptability of an innovation on a project is dependent upon the coincidence of the motivation and capability. These are described as innovation initiators and enablers (Figure 1).

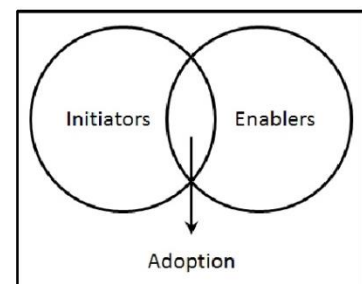


Figure 1. Adoption as confluence of initiators and enablers

In the presence of only one of these factors, the likelihood of an innovation succeeding is limited. This paper points towards a future research agenda exploring how constraining conditions might be exploited to introduce other innovative materials in pursuit of resource efficiency.

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## **Appendix I – A Copy of Jones, Martin and Winslow (2017)**

This article can be found at the Structural Engineer Magazine by following the link below.

[https://www.istructe.org/journal/volumes/volume-95-\(2017\)/issue-1/innovation-in-structural-engineering-%E2%80%93-the-art-of](https://www.istructe.org/journal/volumes/volume-95-(2017)/issue-1/innovation-in-structural-engineering-%E2%80%93-the-art-of)